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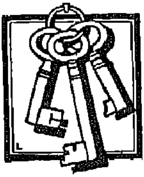

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SCIENCE AND EDUCATION

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SCIENCE AND EDUCATION

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CAMBRIDGE
AT THE UNIVERSITY PRESS
1946

"During the past third of a century, changes in the conditions of life have come about, more profound than any in human history. Distance has been virtually abolished; cognisance of events has become simultaneous throughout the world; all men have become neighbours. Fresh discoveries open up undreamed-of potentialities for good or for evil, but their proper use demands correspondingly high ethical standards.

While only a century ago the village was an almost self-sufficing unit, to-day the world is our unit. To such a disturbing change of outlook and of obligations, we are not yet attuned, and we must readjust our way of living, for only by the fullest and freest adaption of ideas to new conditions can this readjustment be achieved. Intense mental effort and clear vision are now needed."

(From a Declaration of Scientific Principles approved by the Council of the British Association and presented to the Association's Conference on Science and World Order, 1941, *by the President, Sir Richard Gregory.)*

PREFACE

THE idea of this book grew during the past five years from discussions on the relations of science and education to some of the problems of our time. Its chapters finally began to take shape during otherwise peaceful hours spent in home-guarding a water tower in the summer of 1940.

The contents of books and of correspondence concerned with the shaping of the post-war world emphasise two points as of fundamental importance. One is the necessity for a fuller and wiser application of scientific knowledge and of the scientific attitude to social questions; the other is the need for a reorganisation and reorientation of our education. We have tried to outline the ways in which the two problems are related by examining the position and potentialities of science in education; it will be admitted that to-day the reactions of science on the world, and consequently on education, are of quite special importance.

The recent meeting of the British Association was but one piece of evidence, among many, that statesmen as well as scientists are awake both to the urgency of the social developments raised by advancing scientific knowledge and to the part which such knowledge must play in the creation of a happier world order. Such considerations impose a special responsibility on our education in science, whether it is the specialised training of the future scientific worker or the general education of the ordinary citizen.

We have attempted to analyse this responsibility in terms of the technical possibilities of a scientific age. Then we have asked whether our present education is adequate to make full use of these potentialities. Lastly, we have suggested changes necessary if the proper foundations are to be laid for the application of the new knowledge for the good of mankind. These are questions which concern not only the teachers of science but all those who have an interest in education whether as teachers, parents, or citizens.

Our thanks are due to Sir Richard Livingstone, Mr E. G. Savage and Mr K. B. Hutton, Dr H. M. Sinclair and Dr J. H. Humphrey, who have read the manuscript and offered friendly advice and criticism. We owe a special debt to Professor Ernest Barker for his encouragement and for his suggestions and help both with the manuscript and the proofs; and to Miss Humby and to Mrs C. M. James, who have helped us in many ways at every stage of our work. The authors alone are responsible for the opinions expressed in the book.

February 1942. S. R. H.
E. J. F. J.

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SCIENCE AND EDUCATION

CHAPTER I

SCIENCE AND SOCIETY

> "Science is the great instrument of social change, and its silent appropriation of this dominant function...is the most vital of all the revolutions which have marked the development of modern civilisation."
> LORD BALFOUR.

IT is now generally agreed that considerable changes are necessary in our educational system, and the number of recent books on education bears witness to the existence of such a belief. But before we can suggest reforms of our education the dominant social forces of our time must be considered. Educational change cannot occur in isolation from society: it must be directed towards certain social ends and designed to bring education into line with a changing social environment. The indissoluble connection which should exist between the pattern of the educational system and the social order for which it is preparing the citizens has been realised by most educational thinkers from Plato onwards. But in practice, educational methods may become unrelated to the social background and this has certainly happened in our contemporary civilisation. The past three hundred years have seen so great a change in the conditions of life of a great part of the human race that man is now living in a new world. With these changes education has not kept pace; and there has developed a dangerous gap between education and the needs of the social system for which it should be a preparation. The modern emphasis on "education for citizenship" is itself an indication that a gap has in fact developed between education and social needs, for to educationalists of earlier times such a phrase would have been meaningless, since all education was for citizenship.

It is towards bridging this gap that most educational reformers are now working. They are approaching the problem from a variety of different angles—political, religious, administrative, and specifically educational. It is the object of this book to emphasise afresh another aspect of the situation. In our view one of the principal causes of the maladjustment between education and the needs of the world lies in the fact that the new scientific knowledge, from which the recent profound changes in society so largely spring, is itself only very imperfectly incorporated in our education. If this is the case, then one of the most necessary steps towards giving our teaching a greater relevance to the needs of the modern world is a reassessment of the place of science at all levels of education.

To state that one of the determinative factors in our society is scientific discovery is to be guilty of a platitude. It is, indeed, so often said that it is therefore accepted without the thought necessary to bring a full realisation of its meaning. In spite of the hours spent in our schools in the teaching of science, in spite of the number of books produced each year that popularise various branches of science, it is nevertheless true that the majority of educated men and women remain resolutely unaware both of the way in which such discovery has shaped society in the past or of the way in which it might revolutionise it in the future. Such unawareness reveals a fundamental inadequacy in our education. If what is, perhaps, the greatest moulding force of contemporary civilisation is only half understood by the majority of citizens, then here is an obvious direction for reform if education is to be brought into closer relationship with the needs of life. Before we can truly assess the place of science in education, however, we must consider some of the directions in which scientific knowledge has altered the world in which we live, though to many readers such a survey may be the re-telling of a familiar story.

THE FUNDAMENTAL NATURE OF SCIENTIFIC DISCOVERY

The social effects of science are often misunderstood; they are thought of as purely superficial. Science to the ordinary man provides the trimmings of life without appearing in any way to affect fundamental issues. To him, "science" means comfort or speed or safety, or increased weapons of destruction; it is thought of in terms of motor-cars, or anaesthetics, or radio, or poison gas. The use of the phrase "you cannot change human nature", suggests an immutability for human thought, and the belief that it is unaffected by technical environment. It is, of course, true that in certain directions such immutability does seem to exist. The primitive instincts of men appear to remain unchanged in content, if not in expression, through the centuries. But above this unchanging basis, technological advances have produced so many new problems and so many new opportunities that they create not merely a new physical background, but also a new intellectual, and moral, environment. It may be true, as is so often pointed out, that the criteria and incentives of moral action remain substantially permanent, but technical changes alter completely the resources for envisaging and practising a new social ethic.

It is easier for us to see the impact of technical discovery upon society in the more remote past than in the last two centuries. Thus everyone knows how profound was the effect upon civilisation of the discovery of printing and the production of inexpensive books, though even in this case it is doubtful whether the full repercussions are fully grasped. Here is an obvious example of a purely technical discovery that altered not the physical basis of life, but the whole intellectual climate in which the Western world developed. The potentialities of Renaissance, Reformation, revolution, democracy, and propaganda implicit in the mere multiplication of printed words could have been foreseen by a fifteenth-century observer possessing sufficient technical and social vision. It may be held that such a discovery as that of printing belongs more to the sphere of invention than to that of science and that a distinction should be drawn between them. In fact, however, all inventions rest upon scientific principles, and development of scientific ideas results in a rapid stimulation of useful invention.

A history of the world might well be written in terms of such simple yet immensely potent technical innovations as the discovery of the wheel, of the lever, of the use of metals and of artificial irrigation. Before the Renaissance such discoveries happened at comparatively long intervals. Time was available for man to adjust himself to the changes which he himself was bringing about in his environment. Since the Industrial Revolution, however, this time lag has not been occurring. Invention has followed on invention, theoretical advance upon advance, with such bewildering speed that man has been denied the time to acclimatise his thought and his social morality either to the latest achievements, or to the prospect opening before him. He has simply not realised the magnitude or the significance of the changes in his environment, and has failed to see beneath the changing physical surface the deeper problems he has himself created.

THE CHANGES OF THE LAST TWO CENTURIES

So great are the changes of the past two hundred years that it is difficult to find the most outstanding examples: so obvious are those changes that it may be thought unnecessary to mention them. And they might, indeed, be taken as known were it not for the fact already mentioned that many people accept them as part of their lives without realising their origin in advancing scientific technique, and without realising their significance for the future. Were the nature of the problems realised to the full, then it is probable that society could adapt itself far more rapidly to their solution than it shows any signs of doing now.

Perhaps the most obvious contribution that science has made to social organisation is that it has put potential plenty in our reach instead of the scarcity of the past. The plain obvious fact is that it is no longer necessary for man to labour to wring subsistence from a reluctant and inimical nature. With our present resources of agriculture, chemistry, and transport, it is well within our grasp to abolish the possibility of want for every human being. For the wealth of goods which science and modern industry have produced, the majority of men and their rulers are at present psychologically and spiritually unprepared. The habits of thought which grew up in a past of scarcity cause many to behave as if technology and mass production had not brought within the reach of all many of the goods which formerly were available only to the wealthy. It is true, of course, that the possession of such goods will not ensure happiness, or make their owners necessarily better men, but few of those who have themselves known poverty will doubt that the era of greater general wealth will immensely raise the happiness of mankind. Yet a very great deal of our economic and social thought, and still more of our behaviour, is based on the assumption that goods are limited in quantity, and that one man's gain can only be secured at another's loss. Here is a central point at which social thought has not adapted itself to technical advance, and it is by reason of this lack of adjustment between a scientific technique and a pre-scientific economic thought that we are periodically faced with crises of "over-production". We are, as has often been pointed out, living in a world in which, if too much is produced, people may starve.

This central and obvious feature of our society is connected with the detailed results of scientific advance. Those results have included in the past three centuries a great conquest of substances, of distance, of energy, of disease, and of irrational fear. To realise clearly how great has been this conquest it is only necessary to recall the nature and the magnitude of some of the changes that have occurred.

THE CONQUEST OF POWER

In 1700 the sources of power at man's disposal were water, wind, and to a very slight extent, heat, but greater than all these was the work of animals and men. Since then a revolution has occurred by which the heat derived from coal has become the dominant power source of the world. A new source in oil has also been developed. But more important still, the development of our knowledge of electricity during the nineteenth century saw the creation of a new and potent power supply. This power supply was at first dependent upon coal: to some extent this is still the case. An ever-increasing quantity of electricity is, however, derived from water power, and this means of generation will be developed much further in the future, for electrical power has the remarkable property that it can be made available at great distance from its source. The revolution in power production has meant not only the tapping of new sources of power, but also an enormously large increase in the amount of power available. We have passed in a century or two from a world in which the standard of mechanical work was what a man could accomplish with his muscles, assisted by the simplest mechanical contrivances, to one in which we think in units many millions of times as great. We are told that 100,000 men working at intervals for thirty years built the Great Pyramid. Such an amount of labour is insignificant by modern standards. If we assume that one continuous horse power in a machine is equivalent to 30 slaves each working an 8-hour day, the present output of electrical power alone is estimated at 130 million horse power, which is equivalent to 4000 million slave power, about two for each inhabitant of the earth.

The social effects of this extraordinary revolution in power production have been correspondingly profound. The initial effect of the use of coal to drive machines was, of course, a concentration of population round coal fields. The people went to the source of power, and the early nineteenth century saw the growth of all the horrors of black ugliness that disfigured then, as they still do, a society which attempts to profit from forces the magnitude of which it does not fully understand. With the growth of the factory system other new social phenomena made their appearance. The technique of mass production, arising directly from the ready availability of practically unlimited power, has created several problems only the fringe of which is yet touched. Even at the beginning of the nineteenth century a change in the class structure of industrialised countries was apparent; we see the creation of a large working class, and a comparatively small new class of industrialists, to which the further development of science has added the various technicians as an intermediate class of great importance. A further result of the conquest of power, and one not yet fully realised, is the possibility of reducing hours of work, so that whereas to the peasant of the seventeenth century, or the "hand" of the early nineteenth century, leisure was a very brief interlude in a life of almost unremitting toil, we are now within measurable distance of the time when the working hours will be less than the hours of free time not spent in sleep. The scope this will give to all for the development of personal interests will be welcomed by the many, although some few, generally those of over-ample ease, are heard to speak critically of anything less than an 8-hour day. Whether we welcome or deplore it, this spread of leisure time remains a profound and inevitable change, which must be reckoned with in social reconstruction.

THE CONQUEST OF MATERIALS

These are some of the results of the conquest of power. They have been reinforced by the accompanying conquest of substances. The spectacular rise of chemistry in the last 150 years has enabled man to provide the materials necessary for the construction of his industrialised civilisation, and it has had in addition other effects. Without this remarkable development of chemical knowledge the tempo of the industrial revolution could not have been maintained. Hand in hand with the application of new machines has gone the investigation of metallurgical processes that has made such machines possible. Consider the production of iron. In Great Britain the annual output in 1700 was below 20,000 tons. Two hundred years later 90 million tons of steel were being used every year. On a similar scale is the increased output of the other common metals, and of previously unknown ferrous alloys. The industrial use of the light metals aluminium and magnesium has only just begun.

The corresponding development of organic chemistry has put at our disposal drugs, explosives, dyes and anaesthetics without number and apparently without limit. These spectacular triumphs are familiar enough to the ordinary man; they are, indeed, the aspects of scientific discovery which come first to his mind. But their effects on our civilisation go much deeper than their effect on the amenities of life. For example, it is only advances in pharmacology that have made possible the utilisation of the tropics, and the advance of medicine has brought not only alleviation of suffering but also the much more fundamental problem of an ageing population. More obvious, perhaps, is the decay of old industries and the rise of new, associated with the production of new substances. Related to this is the promise that synthetic chemistry holds out of greater local self-sufficiency. If science on the one hand is knitting the world into a greater unity by the annihilation of distance, it is also making individual communities less dependent for essential substances on distant sources, by giving them the power to synthesise these substances themselves, or to develop satisfactory substitutes for them. The opposite or unifying tendency is exemplified in a number of obvious ways. The development of transport and the discovery of methods of preservation of foodstuffs would have already banished famine from the world if human sympathy had found the necessary expression and organisation. By newspaper, telegraph and wireless we are in touch with all the world. This unification is bringing its own special problems. The ill-fed and ill-paid labourer of the East is now more than a challenge to our humanity; he may bring unemployment to the homes of our own people whose trade he destroys.

THE RAPIDITY OF SCIENTIFIC ADVANCE

These advances of knowledge, and the far-reaching social repercussions that follow from them, are remarkable not only for their extent and for the rapidity with which they occur, but also because that speed itself is constantly increasing. Man is at no point faced with an even approximately static society, from a technical point of view. He has at no time in the last two centuries been given a breathing space for social readjustment, and the prospect of such a breathing space becomes steadily less. The reasons for this increasing rate of scientific advance are twofold. In the first place the industrial revolution showed that scientific research paid. This has meant that what was formerly the occupation of a few amateurs has now become the profession of countless specialists. Further, it is being more and more widely realised that researches which are apparently quite remote from practical problems may nevertheless yield revolutionary practical results. Again, scientific work, quite apart from practical results, has become a much more common direction of study by reason of its triumphs in the practical field. The ideal of "pure" science has been revived; that is to say science has been studied from the motive of accumulating knowledge with no thought of the practical uses to which that knowledge may be put. Indeed, many subjects have been studied which apparently could have no practical usefulness at all. Actually the theoretical advances which have resulted from this kind of work, in spite of the non-practical attitude behind it, have had the greatest possible social results.

The other chief reason for the increased speed of scientific advance lies in the inter-connectedness of the sciences. Discoveries in one field have led to very rapid progress in directions superficially remote. Thus the development of electrolytic processes opens the way to large-scale production of light metals, which may radically alter building technique, and which certainly makes possible the construction of modern aircraft. The investigation of the discharge of electricity through gases leads to the discovery of X-rays, which revolutionises certain fields of medical diagnosis and treatment, enables us to study the nature and strengths of metals, and furnishes information of the greatest theoretical importance about the structure of matter. Because we can scarcely ever limit the possibilities of any research, because research is now subsidised for its own sake, and because advance in one subject will often bring great advance in another, we are faced with a world in which the growth of scientific knowledge is not only extremely rapid, but in which that growth will become progressively more rapid, at any rate in the immediate future. When, further, we attempt to realise the social changes brought about by the scientific advance even of the last two hundred years, we find ourselves compelled to deal with a social situation that is rendered at once challenging and bewildering. The most significant fact in the contemporary scene is that a great new force is at work in the world, the force of a new field of knowledge, that has altered and is altering not only superficial and material adjuncts of our life but the whole nature and possibilities of social organisation.

Though a number of the problems mentioned above are not scientific problems in the ordinary sense of the word, yet there can be little doubt that society would be better able to deal with them if it approached them scientifically. Since they spring from scientific advance, it is only natural to suppose that we can only diagnose and anticipate them if we ourselves have some knowledge of the forces that produce them. In fact, society as a whole is lacking in that knowledge. It may well be argued that one of the fundamental causes of the present ills of Western civilisation is the impact upon it of scientific techniques, while its whole approach to life remains stubbornly pre-scientific. This fatal division between resources and awareness is shown in any number of ways in almost every department of our life. It is perhaps, therefore, worth while to exemplify it.

There is a well-known story of Gladstone that, being shown Faraday's fundamental experiments on electromagnetic induction, he remarked: "But what is the good of it, Mr Faraday?" The story may be apocryphal, but it illustrates an attitude of mind that is real enough, and characteristic not only of the statesmen and administrators of the nineteenth century, but also all too prevalent to-day. The educated man is very ready to admit the achievements of science. But these achievements are connected in his mind with the spectacular, the material and the comfort-producing, rather than with opportunities for social change. He would not see, as Gladstone did not see, in Faraday's work a further stage in the conquest of power. He would not see latent in that conquest the possibility of replacing the squalor inseparable from a coal economy by cleaner factories, no longer concentrated in sordid industrial towns with their constant reproaches of ugliness and ill-health. Because of this failure of the leaders of thought to recognise in science an instrument for social progress, both society and science have suffered.

THE LACK OF ADEQUATE RESEARCH

To-day we are beginning to hear of the "frustration of science". The life-blood of scientific progress is research: that is to say, without research we are not in a position either to discover new knowledge or to use that knowledge for social ends. Yet a characteristic of our society is its starvation and misdirection of research. In his most important book, *The Social Function of Science*, Professor Bernal calculates that only £4 million per annum, or 0·1 per cent of the national income, is devoted to research work of all kinds, and of this 25 per cent goes to war research. It is quite evident from this and from other evidence that Professor Bernal produces that society is as yet completely unaware of the social benefits that might arise from an extended and co-ordinated programme of research work. Co-ordination of research must not involve any limitation of that freedom which is so vital to the true development of science. If the spirit of free scientific inquiry were forced into some rigid pattern, the remedy would be as bad as the present disease. The work of the academic research scientist must remain a matter for the individual in consultation with his director—though here a growing realisation of the social relations of science may exert a modifying but never a repressive effect. It is rather in the industrial field that the present patchwork of secret and limited researches should be replaced by long-term programmes carried out by workers with the fullest exchange of information and directed towards the solution of the technical problems of the community. Purely from the material point of view it has been demonstrated again and again that research is the most paying industrial investment that can be made. Dr Lovell, in his valuable little book *Science and Civilisation*, quotes figures which show that "From six research associations alone, at the expense of £400,000 in all, have come researches which have made possible in practice a saving of £3,200,000 per annum".

But perhaps still more important than this is the failure to grasp the importance of pure research. It is becoming more and more clear that the researches which have the most remarkable practical results are often those undertaken without any practical end. These are, however, usually researches of a long-term character. They must be subsidised for considerable periods without hope of definite or immediate results, and it is precisely the wisdom of this course that a scientifically ignorant society fails to grasp. The indefensible distinction between "pure" and "applied" has spread to the scientists themselves. In the last century we see the lamentable spectacle of academic scientists forgetting the attitude of their predecessors to the extent of glorying in the uselessness of their discoveries. This attitude is fatal to the healthy development of science and society for three reasons. In the first place, it rests on the extraordinary assumption that useless knowledge is in some way a more admirable thing than knowledge which helps in the improvement of man's social conditions. It perhaps springs from the unfortunate fact that applied science has been mainly devoted to ends of purely material comfort, or to destruction, rather than to genuine social betterment, but whatever its origins the belief in knowledge for its own sake is one that should be recognised as stifling and obscurantist. Secondly, the belief in the distinction between pure and applied science is one that is constantly being broken down by experience. No research on atomic structure, for instance, is so remote that it will not provide information concerning the structure of materials. Thirdly, the distinction is socially dangerous, for it has led the scientist to take up an attitude of extraordinary irresponsibility concerning the effects of his discoveries. He has conferred on society the widest powers, yet in the exercise of those powers he has had no share and no responsibility. For this state of affairs society is itself partly responsible: but blame also attaches to the scientist, who has all too often been content to work in an ivory tower of pure research, isolated from the world which his work is revolutionising.

Misdirection of Research

Another result which the general lack of scientific awareness has had upon research is in the direction along which that research has progressed. As the industrial revolution developed, industrialists were forced, usually slowly and reluctantly, to recognise that research paid. Reference has already been made to the emphasis thereby laid on short-term research. But it is also true that the profit motive canalised scientific study into too narrow channels, and had other undesirable results. Researches carried out under these conditions were usually secret and unco-ordinated; the pursuit of scientific knowledge was thus impeded, and its pursuit rendered less efficient, by motives of private profit. Its whole outlook became unbalanced. The physical sciences were, and are, subsidised comparatively heavily, whereas the biological, social and even medical sciences are starved. The British Medical Research Council in 1939 was subsidised to the extent of only £195,000; yet, as Dr Lovell points out, the annual loss to this country through ill-health is of the order of £300 million, and in India 1½ million people die yearly of malaria, an entirely preventable disease. A most striking way in which the economic organisation of society frustrates the free progress of science is in the "freezing" (i.e. the buying up and suppressing) by large firms of patents which if exploited might well have results of great social value.

To summarise the present position of research it may be fairly said that the free development of scientific knowledge is starved, hampered, and misdirected, because, though using some of the results of science, our society is too ignorant of its potentialities to demand their fullest study and exploitation.

THE FEAR OF SCIENCE

Society is, however, unenlightened towards science in many other ways besides its attitude to research. There is a genuine fear and distrust of scientific advance. This fear takes many forms, and arises from many causes. It may well be part of the general distrust of the intellect which many observers have noticed as characteristic of our age. But it is partly more comprehensible than that.

There is in the first place a general and reasonable fear of the destructive instruments which science has placed in men's hands. It is the tendency voiced by a bishop when he remarked that it would be a good thing if scientific research could be suspended for ten years. Why he specified so short a period is uncertain, for if our social and spiritual leaders maintain their present detachment from the advance of scientific knowledge, not ten but a thousand years' holiday would be more appropriate. It is not, in fact, true that any special capacity for evil lies in scientific discovery. Any new knowledge may be applied either to good or evil ends; and science has merely supplied such knowledge in unparalleled abundance. Faced with that fact, many thinkers at present merely complain that our material advancement has outrun our moral development, and some seem anxious to return, like Peter Pan, to the racial childhood they should be leaving. The real task for men of good will is to overcome this spirit of defeatism and to make themselves and society aware of the possibilities for good in the new knowledge. The same answer must be made to those who fear that the advance of science will lead us to a soulless and mechanical "Brave New World", in which technology will have triumphed over aesthetic and moral values. This can only happen when those concerned with such values divorce themselves from the new knowledge. In any case, this fear of scientific discovery, from whatever source it arises, can only be a sterile and uncreative force, for whether we welcome it or not, scientific knowledge will go on increasing. The remedy for the misuse of knowledge is greater knowledge, absorbed into a genuinely enlightened and progressive social pattern.

That we are far from accomplishing this fusion at present is shown by all sections of the community in a hundred ways. The prodigious sale of patent medicines, the credulity through which the quack and the bogus expert command an audience, are evidence of the obvious and almost universal lack of scientific knowledge. It is possible in the contemporary world to see a whole country rich with the technical devices of science, yet capable of accepting as fact social theories incapable of withstanding a moment's scientific criticism. The same credulity may be seen, too, in the works of some of our writers, say on eugenics, where the conclusions seem to be based more on political viewpoint than on the facts from which a scientific understanding of the problems could be obtained. Here we have not only a lack of scientific knowledge, but of scientific approach also. Of the absence of a scientific method examples might be indefinitely multiplied. Consider the handling of Air Raid Precautions. Experimental work has, of course, been done by Government departments on these problems, yet there was for many months astonishingly little clear and definite guidance available on such subjects as the effect of blast upon windows, although these problems are easily and obviously capable of an experimental solution. In every department of contemporary life there is an extraordinary deficiency of scientific knowledge and approach. Prejudice, vested interest, wishful thinking, are all allowed to settle questions which are capable of passing, by experiment, from the realm of opinion to that of ascertained fact.

What Science could do

The result of this lack of awareness in our society is the astonishing gap between potential and actual success in dealing with the new opportunities and problems that increasing knowledge has brought. Man's control over his physical environment may be greater than ever before in his history, yet the corresponding increase in his social well-being is still unrealised. It is difficult to set out, at any rate in a short space, what science could do for society were it better organised, and were society more aware of its possible contribution. One too easily slips into vague prophecies of Utopian bliss. Yet there are few departments of life that would not be enriched by scientific knowledge and approach.

A century of modern medicine has done much. Smallpox and cholera have been swept away from Europe; malaria and yellow fever have been made preventable diseases; the expectation of life has been increased by many years. Yet preventive medicine is still in its infancy, while biochemistry with its work on vitamins and hormones has still only touched the fringe of the problems of human nutrition and development. The deaths from entirely preventable disease are still shockingly numerous. That our society should go on permitting the attack of tuberculosis upon its slum children is due, no doubt, partly to the selfishness of an acquisitive social structure. But it is due also to a failure to grasp that such a state of affairs is at any rate partially remediable. Again, the smoke-laden squalor of industrial cities is admittedly deplorable. To some extent it must be regarded as inevitable while a coal-steel economy persists. But in a society fully aware of the power at its disposal, can one doubt that research would be pushed forward in a more vigorous and co-ordinated way towards the admittedly distant goal of an economy resting more on electricity and the use of light metals? The development of "plastics" has put an entirely new range of materials at our disposal; materials admirably adapted, for example, to the production of bright, well-designed furniture for poor homes. Yet the exploitation of these substances for social ends is left almost entirely to the unco-ordinated research of private firms. Whatever field of material activity we investigate we find that science could make enormous contributions to human welfare, were it but used. Consider the immediately pressing problems of nutrition. In a recent important book, *Science and War*, we read: "The minimum daily requirement of each of the ten or so most important vitamins together with a few important minerals (such as calcium, iron, and a trace of copper) could easily be incorporated in a biscuit which would be distributed free, or at a very low price, to the whole population. The annual cost would be less than £2 million and the saving in health and efficiency immeasurable. This figure of £2 million should be contrasted with the vast sum (approximately £50 million) that is being spent in subsidising British agriculture to an extent that is inadequate to provide these vitamins."

In the wider and more general field of the organisation of labour there is no doubt that did society so desire, research could cut down the times spent on dirty and dreary jobs to a fraction of the present figure. The successful development of psychological aptitude tests gives us hope that suitable occupations may be found in which the powers of the individuals may be used to the best advantage. The solution to one of the perennial problems of society is within our grasp—the problem of how to manage without slaves or at any rate without a large and more or less depressed "working-class". After the disappearance of such classes and the mentality which their existence engenders, there will still be a good deal of unpleasant and monotonous work to do, and it may well be desirable to give higher reward for such occupations, instead of leaving them to the unfortunate who have little choice of other work.

Besides these alterations in the material control of man's environment, science and the scientific method could well bring about profound modifications in our mental background. As the light of science grew in the seventeenth century the legal and illegal murder of witches passed away from Western Europe. Science brought relief from the irrational fears which in the Middle Ages had condemned perhaps three-quarters of a million poor creatures to death. We may well hope that an increasing knowledge of the roots of mental disease and of delinquency may bring a new hope for those who to-day spend their lives in the shadow of other irrational fears.

These are random, and in some cases perhaps minor, examples of the revolution in social wellbeing that a whole-hearted pursuit and application of scientific knowledge might produce. What, then, is the obstacle which impedes our progress towards the realisation of these ends? What is the solution to the problems of adjustment and utilisation of new knowledge with which we are showing ourselves so conspicuously unable to deal? There can be little doubt that the answer to these questions is in our education. If our administrators are too ignorant of the achievements and potentialities of science to make full use of them, then their education has been lacking. If the mass of our people are unscientific in a hundred ways, if their minds are riddled with irrational fears and superstitions, then the remedy is in the schools. For if it is the function of education to make knowledge available for social ends, ours has been too slow to realise the significance of the new knowledge of the last two centuries. To a great extent the failure of our social adjustment arises in a divorce at the school level between this knowledge and the creation of a social conscience. It is repeatedly pointed out that science has nothing to do with values, and cannot teach people to be good. This is partly true. But science can put at the disposal of the good man knowledge that will enable him to realise his aspirations in a hitherto undreamed-of way. If our education is seeking to produce good citizens it is at present failing in its object, in so far as it only very imperfectly equips them with the knowledge and the vision that science can bring. That the present problem is at root an educational one is realised by those scientific writers who are most socially aware. Thus Lovell writes: "One must first create an entirely new outlook through the basis of education. This is neither difficult nor impossible; in fact the best modern educational methods already do so." As regards practical suggestions, unfortunately, Dr Lovell, like nearly all similar writers, is vague. Too often these pioneers of scientific humanism pin their faith to the extreme "modern" schools. Whatever the merits of these schools, they are, in fact, in such a tiny minority that they cannot affect the real core of the problem, which is in post-primary education as a whole. Whether or not one agrees with the criticisms of our education voiced above, it is clear that the position of science in schools, its methods, its aims, and its achievements must be submitted to the closest scrutiny.

CHAPTER II

SCIENCE IN OUR SCHOOLS: THE PAST AND THE PRESENT

THE BACKGROUND

IN the previous chapter an attempt has been made to state and justify the view that our civilisation is unaware both of the extent to which it has been modified by scientific discovery in the past and of the potentialities that extended and co-ordinated research opens for the future.

In the present chapter it is proposed to show that this lack of awareness has its origins in our educational system.

The history of education in England makes clear two central facts about the position of science in our schools: the introduction of science into the curriculum has been too slow and halting to keep pace with the demands of our society, and the science introduced has suffered under the stigma of being a purely "technical" study which has never been correlated with "cultural" education. A fundamental weakness has thus been introduced both into our education and our society. The weakness did not make itself felt until the end of the eighteenth century, for it was not until that time that scientific and technical progress swelled from a stream to a flood. Thus education was not then violently divorced from the needs of contemporary life. If it was conservative, or limited, or inefficient (and at times it was all of these), it did at any rate try to prepare the child for the world in which he would live and work. In the application of most branches of technology, society was largely static from the Middle Ages until the seventeenth or even the eighteenth century. There was a time lag before the technical repercussions of the Renaissance spirit were fully developed. Hence it is not surprising that during those centuries the curriculum of the higher schools changed hardly at all. It was based almost exclusively on Latin grammar and literature, with a later admixture of Greek. As Leach has said (*Educational Charters*): "In nothing, not even in Religion, has the innate conservatism of the human race been more marked than in education. It is hardly an exaggeration to say that the subjects and the methods of education remained the same from the days of Quintilian to the days of Arnold, from the first century to the mid-nineteenth century of the Christian era."

That this should have been the state of affairs until the seventeenth century is comprehensible enough. Latin was a language universal among educated men, and only those who were to be educated in an academic way went to the "Grammar" schools. They formed the high-road to the professions of law, theology, and medicine, and the further specialised knowledge required for the pursuit of these subjects could be acquired at the university. As the statutes of Winchester College (1382) say: "experience, the mistress of all things, plainly teaches that grammar is the foundation, gate and source of all the other liberal arts without which such arts cannot be known, nor can anyone arrive at practising them; considering moreover that by the knowledge of grammar, justice is cultivated and prosperity of the estate of humanity is increased...".

THE SEVENTEENTH AND EIGHTEENTH CENTURIES

Such a view of the content of education was certainly justified up to the sixteenth century, and under the first impact of the new knowledge the schools showed some capacity for adaptation. Greek became more common and some response was made in a number of schools to the complaints of the new commercial interests that the education was not practical enough. The teaching of cosmography, navigation, and more advanced mathematics made its appearance, especially in schools near the sea-coast. This is particularly noticeable in the seventeenth century with its marked interest in scientific progress. The most important symptom of this interest was the foundation of the Royal Society in 1662, and it is significant that suggestions were made at this time for the creation of a specifically scientific school.

In the eighteenth century the criticisms of the traditional curriculum became more marked. As the commercial interests became more important they became more aware that their educational demands were not being satisfied. One of the results of this middle-class revolt against contemporary educational values was the founding of a number of Nonconformist Academies. These schools, important both in themselves and in the many small schools which copied them in curriculum and in aims, were to have a considerable effect on the nineteenth-century reform of the older institutions. Professor Clarke, speaking of them in his important book, *Education and Social Change*, says: "If this school of thought had a key idea of culture, the word to express it would be Science rather than Language. Like the ruling class, they thought of education in terms of culture, but with a significant difference in content....We must relate them, therefore, to the Royal Society, to the inventions of the eighteenth century, to the beginnings of the Industrial Revolution, and to the modes of thought which gave rise to the revolutions in America and in France."

It is easy, however, to over-emphasise the importance of the contribution of these academies to scientific education. Though they did sometimes include science, particularly physics, in their curricula, their principal preoccupation was with commercial subjects and what would now be called "modern studies". At the beginning of the last century there was in fact practically no actual education in science in any type of school.

THE NINETEENTH CENTURY

During the first half of the nineteenth century the application of scientific knowledge to social purposes, the process that we call the Industrial Revolution, acquired an enormous and ever-increasing momentum. Every department of life felt its effects. A host of new problems, social, political and technical, appeared. How far did our education reckon with the new knowledge or transmit it in a form that would lead to the wise application of the vast new powers? The answer is "Not at all". This answer will be found expressed in various ways in the evidence given before the various commissions that were set up from 1860 onwards to consider an educational system that had obviously become divorced from social needs. The exaggerated conservatism to which we have already referred prevented adaptation to the rapidly changing environment. The absence of change in a curriculum dating from Quintilian was tolerable until the eighteenth century; its persistence to the days of Arnold was a tragedy. Some slight signs of change become evident in the middle years of the century; thus Rugby introduced the teaching of Natural Philosophy in 1837 and built a laboratory in 1854. The state of affairs revealed by the Public Schools Commission of 1864 and the Endowed Schools Commission of 1868 shows, however, that in fact the education of the upper classes, of the future governors and administrators of the country, was for all practical purposes the same as it had been since the fifteenth century.

Before the Clarendon Commission we find Faraday saying in answer to the question "But you consider that those studies [i.e. any scientific subjects] have been overlooked?" "As far as regards education, almost entirely." The general report of that Commission said: "Natural Science, with such slight exceptions as have been noticed above, is practically excluded from the education of the higher classes in England. This exclusion is in our view a plain defect and a great practical evil."

A similar opinion is expressed in the report of the Schools Inquiry (Taunton) Commission of 1864–8: "Nor would it be wise", say the Commissioners, "in a country whose continued prosperity so greatly depends on its ability to maintain its pre-eminence in manufactures, to neglect the application of Natural Science to the industrial arts, or overlook the importance of promoting the study of it, even in a special way, among its artisans." Here, it will be noticed, the virtue claimed for science is a purely material one. There is no suggestion of opening up a vast new field of knowledge, but rather a recognition that science enables men to be rich.

The fact that these Royal Commissions should have invited scientists to appear before them and should have included recommendations on science teaching in their reports does, however, show that a new spirit was abroad. From the middle years of the century T. H. Huxley, Herbert Spencer, Canon J. M. Wilson and others were preaching a crusade on behalf of science in education. The spread of science teaching was, however, very slow. In spite of Huxley's efforts, his courses for teachers, his brilliant popular lectures, the education of the upper middle classes remained almost entirely non-scientific until the present century.

The Rise of Technical Education

In one direction, however, the efforts of Huxley and his fellow-workers did achieve considerable results. This was in the field of technical education. Here there was a definite economic incentive for reform. In his evidence to the Public Schools Commission, Faraday drew attention to the superiority of foreign countries in the sphere of technical education. As the industrialisation of other countries caught up with that of England, this superiority in their organisation attracted increasing attention and gave rise to increasing alarm. The international exhibitions which followed the Great Exhibition of 1851 showed that this country was not in fact keeping abreast of its competitors in the field of applied science. In 1881 a commission was appointed to "inquire into the instruction of the industrial classes of certain foreign countries in technical and other subjects for comparison with that of the corresponding classes in this country".

Its report revealed deficiencies in our scientific education that were the objects of subsequent legislative and financial reforms. New technical colleges were created and a new popular interest in technical education was stimulated by the wise propaganda of Roscoe and Huxley. The demand for improved technical education had its most important results, however, in strengthening the desire for the reformed secondary system which was a necessary pre-requisite for any real advance. This reformation was ultimately realised through the Education Act of 1902. Thus by the end of the nineteenth century it was becoming agreed that secondary education for the lower-middle and working classes must include provision for scientific training.

The recognition of the claims of science in its technical applications was not, however, an unmixed blessing. As Adamson (*English Education, 1789–1902*) says in summarising the report of the 1881 Commission: "...the aim is not culture but ability; the technical schools and their teaching must be carefully suited to the needs and, it might be added, the prejudices of the particular trades resorting to them". It is perhaps true, as Dr Young points out in his appendix to the Spens Report, that the best educational opinion was opposed to any sharp division between liberal or cultural education on the one hand and technical studies on the other. The Report of the Bryce Commission on Secondary Education (1895) did seek specifically to break down this distinction between kinds of education. Yet in practice, at the end of the century, secondary education was of two kinds. The education of those classes which would in fact provide the governors and administrators of the country was for all practical purposes the same in content as it had been since the sixteenth century. On the other hand, such post-primary education as there was for the lower-middle classes either aped the public schools by ignoring science altogether, or else introduced it in its most severely technical and utilitarian forms.

The gulf was made wider by a growing attitude of intransigence on the part of the defenders of classical education. Feeling that their curriculum was in fact out of touch with the current needs of the world, they evolved the conception of "culture for its own sake" that has had such a deleterious effect on the whole of English intellectual life from 1900 onwards. The classics and later, rather grudgingly, history and English were stated to be cultural subjects. Science was associated with the practical, the utilitarian, and the technical, and inherited all the stigma which these epithets could convey. Even the friends of science teaching rarely dared to claim for it a virtue as an essential educational instrument comparable with the older studies. Indeed, as then taught, it could hardly justify such a claim. Never was science presented as a profound movement of ideas with the most far-reaching social possibilities. To have suggested to any but a very few nineteenth-century educationalists that a knowledge of science was desirable as an aid to rational social reform would have invited derision. Yet on the nineteenth-century schools, especially the public schools, the current of events imposed the responsibility of providing the administrators to guide the spectacular development in paternal legislation that was necessary to meet somehow the problems of an industrialised society. The modern civil servant has had to face the administration of industry, of transport, of public health and of labour in a world created by forces that his education did nothing to lead him to understand. He has found it necessary to improvise methods in which his education gave him no training. It is remarkable that in fact he has succeeded at all.

THE POSITION TO-DAY

It may well be thought that since 1902 the whole scene has changed so radically that what has been said is irrelevant to the present situation. Although it will be admitted that it is extremely unlikely that the average administrator over fifty years of age will have acquired at school any knowledge of scientific method or of the achievements or possibilities of scientific knowledge, yet will not his younger colleagues be much better equipped in this respect? Have not all our public schools large and efficient science departments? Have not the creation and development of state-controlled secondary education revolutionised the whole field of science teaching?

It is of course true that the past forty years have seen remarkable changes, and it is certain that the next generation of administrators will have a much greater opportunity of being aware of the contributions of science to human welfare. It is, however, easy to be over-optimistic about the present position of science in education. A close examination of that position reveals a number of ways in which we are in danger of continuing to frustrate the right application of the new knowledge. If we study in any of our higher schools, secondary, grammar or public, the time allotted to science, the content of the science courses, and the treatment of the subject-matter, we shall be forced to the conclusion that scientific studies are not by any means providing the social stimulus and the intellectual training which they should. Also the old division between "humane" and "scientific" studies still hangs like a cloud over all our higher education. As Professor Dewey has said (*Democracy and Education*): "Of the segregations of educational values discussed in the last chapter, that between culture and utility is probably the most fundamental. While the distinction is often thought to be intrinsic and absolute, it is really historical and social. It originated, so far as conscious formulation is concerned, in Greece, and was based on the fact that the truly human life was lived only by the few who subsisted upon the results of the labour of others. This fact affected the psychological doctrine of the relation of intelligence and desire, theory and practice. It was embodied in a political theory of a permanent division of human beings into those capable of a life of reason and hence having their own ends, and those capable only of desire and work, and needing to have their ends provided by others. The two distinctions, psychological and political, translated into educational terms, effected a division between a life of leisure devoted to knowing for its own sake, and a useful, practical training for mechanical operations, devoid of intellectual and aesthetic content. While the present situation is radically diverse in theory and much changed in fact, the factors of the older historic situation still persist sufficiently to maintain the educational distinction, along with compromises which often unduly reduce the efficacy of the educational measures. The problem of education in a democratic society is to do away with the dualism and to construct a course of studies which makes thought a guide of free practice for all and which makes leisure a reward of accepting responsibility for service, rather than a state of exemption from it."

THE PRESENT POSITION: THE PUBLIC SCHOOLS

Let us consider first the place which science occupies in the curriculum of the Public Schools. This is a matter of the greatest importance, since, if we are frank, we must admit that these schools are still largely responsible for the education of our governing classes. Whether we regard it as right or wrong, the position still is that the recruits for the higher ranks of the professions, the civil service and politics are still largely drawn from a fairly small group of schools, represented on the Headmasters' Conference. That this is in fact the case may be confirmed by a few hours' study of ordinary reference books. Thus if we examine the careers of the 17 most senior civil servants we find 12 educated at Public Schools, 4 giving no details of their early education and 1 educated at a state secondary school. Of 27 generals or lieutenant-generals, 17 were educated at Public Schools, 3 educated privately and 7 give no details. Of 36 High Court judges, 30 were educated at Public Schools, 3 at other schools and 3 give no details. Of 43 bishops, 37 were educated at Public Schools and 6 give no details. (Figures for 1940.) The position of science in the Public Schools is therefore of special importance. Superficially that position is very strong. Yet it must be remembered that a boy's qualifications for entry to these schools is judged by his performance in classics and mathematics, with, in practice, a very heavy bias in favour of Latin. This is true both of the Common Entrance Examination and of scholarship examinations, where in many cases an astonishingly high standard is reached in Latin. In other words we are still judging the suitability of a boy for the highest kind of post-primary education mainly by the same criteria as would have been applied in 1400. Nor does this emphasis cease at the age of entry. Until the boy has reached the standard of the School Certificate, Latin still occupies the predominant place in the curriculum of most Public Schools. The number of periods spent on Latin by a Public School boy during the seven years which he usually spends at his preparatory school and his public school before he takes the School Certificate Examination is at present rarely less than seven each week. Thus he will have spent at least 147 term periods on Latin during the time when educationalists are agreed that any specialisation is to be deplored. The amount of time spent on science by a non-specialist (that is a boy not requiring science in his future career) varies very greatly. Usually the subject is started very late and the valuable phase of intense curiosity about the world which is usually shown by boys of 12 and 13 is not directed towards any form of science. The time spent at the Public School is usually about three periods a week for the two years before the School Certificate stage. Thus a Public School boy of 15 or 16 will probably have spent 18 term periods on science and about 150 such periods on Latin. Even a boy who has "specialised" in science and intends to offer a science subject in the School Certificate Examination will often only have studied science for 30 term periods, although the Thomson Committee on the position of science in education (1918) recommended that in all secondary schools the time given to science should be 66 term periods between the ages of 12 and 16. For the same period even the Spens Report, which is scarcely generous in its allowance of time to science, gives 105 term periods to science and mathematics for a "normal" course.

Not only is it indisputable that science is still a very minor subject in the general education of boys in a Public School as judged by the actual hours of teaching, but this state of affairs is reflected in the attitude of mind of the majority of Public School masters. In many schools pressure is brought to bear on the more able boys to prevent them from becoming serious students of science. Under the disguise of "the avoidance of premature over-specialisation" many schoolmasters conceal their belief that science is not a subject which should be taught as part of a general education. For prospective doctors, and others who must learn science for professional reasons, it is perhaps a regrettable necessity, but they do not conceal their feeling that science forms no essential part of the cultural background of the educated man. Such an attitude communicates itself very readily to boys and through them to society. Quite apart from concrete questions of curriculum there is no doubt that the intellectual environment of many of our schools is one in which a man can still boast that he is completely ignorant of science, yet he would regard a similar ignorance of Latin quantities or of the pronunciation of Greek names with pity not untouched with scorn. That such a scale of values should still be widespread among the educated upper classes may appear unimportant. It is when one puts this attitude of polite tolerance combined with placid ignorance against its historical background that its danger is realised, for nothing reveals more clearly the failure of our education to adapt itself to changing social needs.

THE PRESENT POSITION: THE SECONDARY SCHOOLS

It may well be thought that a great deal of what has been said applies only to the Public Schools, and that the newer secondary schools reflect an altogether more progressive tendency. Actually it is doubtful whether this is the case. When the Education Act of 1902 became operative, one of the most significant features in the education given by the newer schools was the way in which they struggled to take over the ethos of the old foundations. This has been particularly true of the Grammar Schools, most of which have become, as regards the class and the needs of the pupils, ordinary secondary schools. Among the educational ideas which they borrowed from the Public School tradition was the distinction between cultural or humane and non-humane subjects. For a number of reasons, social prestige being perhaps the strongest, this distinction has been reflected in the curriculum. The conception that the sciences were useful arts not suitable for those aspiring to administrative positions has to some extent introduced even into the secondary schools, anxious to show themselves not a whit inferior to the Public Schools, a half-ashamed attitude to scientific studies which has had a number of bad effects. They have become in many cases more unfitted to their social purposes than the Public Schools themselves. The attitude is shown in the prospectus of one of the greatest day schools, which until a few years ago contained the statement: "For those boys having no aptitude for classics or modern studies, a science course is provided." In short, many secondary schools have regarded science as a poor and shameful relation in the school curriculum, and they have done this with even less excuse than the Public Schools, who could at least claim that they were meeting the actual demands made by the professions and the civil service.

If we are inclined to be over-optimistic concerning the undoubted growth of science teaching in general education, we must further reckon frankly with the fact that while it has increased in quantity, much of it is still lacking in quality. The deficiencies arise from a number of causes, some of which apply more particularly to the education of those pupils who are not intending to continue their science as a professional study. In the first place, too little care is taken to produce a coherent course so that every boy realises the connection between the successive parts of his science work. It is essential that the teachers plan a course that shall suit as far as possible the average boy at each stage of his development. Some sections of science appeal to the boy of 14 more than to the youth of 17; others are unintelligible if taken at too young an age. There is evidence that these elementary principles of presentation are too often ignored.

There has often not been time to take the pupils beyond the most elementary grammar of the subject. This has encouraged a stereotyped approach because the teachers lacked leisure to experiment and to digress. In some schools the tyranny of examinations has had a stifling effect. The fact that science teaching has so short a history has meant, too, that completely satisfactory teaching techniques have not yet been evolved. All these causes are relevant, but they can all be remedied and there is abundant evidence that in these directions rapid progress is being made. The Science Masters' Association, through its annual meetings and its quarterly *School Science Review*, has done much to improve and co-ordinate the actual details of science teaching.

Some difficulties, however, go deeper than these. The nineteenth-century approach and the directions in which society at present uses scientific knowledge have given science teaching too strong a bias towards the physical sciences. Chemistry and physics, often in their most arid forms, still dominate our school science because they have been thought the most important subjects. One among several reasons for their predominance is that they are the sciences which have paid. Thus our education in science is being partly directed by a profit-making motive rather than entirely by a humane social purpose. Our whole method of presentation is governed too much by this dead hand of nineteenth-century needs. Science is taught as a collection of laws and facts rather than as a constantly growing body of knowledge with social implications of vital importance.

It is encouraging that there has been in recent years a strong movement to replace the more formal courses in chemistry and physics by wider ranges of general science, planned to bring together all the commoner branches into a coherent whole. Nevertheless, it is true that at present our pupils too rarely realise from our teaching that the pursuit of scientific knowledge is a social activity, that science has the power to affect society and society the power to direct science. The relation of science and history is taught, if at all, in the most uninteresting and irrelevant way. The social repercussions of science are relegated to a few isolated industrial applications.

To many teachers these criticisms will appear unjust, for it is true that some teachers and some text-books seek to present a more humane approach. In general, however, it is true to say that though our science teaching has in the past forty years increased in amount, it still tends to present science as a dead body of facts rather than as a living cultural and social force. Some of these criticisms are voiced in Professor Bernal's *The Social Function of Science*, and in the context of this most important book they are especially significant. For example, he says: "Those privileged members of the community who have been through a secondary or public school education may be expected to know something about the elementary physics and chemistry of a hundred years ago, but they probably know hardly more than a bright boy can pick up from an interest in wireless or scientific hobbies out of school hours. As for the learning of scientific method, the whole thing is palpably a farce. Actually, for the convenience of teachers and the requirements of the examination system it is necessary that the pupils not only do not learn the scientific methods, but learn precisely the reverse, that is, to believe, on the authority of their masters or text-books, exactly what they are told and to reproduce it when asked, whether it seems nonsense to them or not." Reference will be made later to some of Professor Bernal's other criticisms.

THE ISOLATION OF SCIENCE

We have said that at the root of the contemporary attitude to science in education lies this fatal division between "humane" and scientific subjects. Science has been associated with a special ability rather than with general ability or with "culture", and little attempt has been made to relate its teaching to the rest of the life of the school or of the community. In the case of the non-scientist the existence of this division starves him of scientific knowledge in the way in which we have described. Its effect on the science specialist is no less deplorable. In many schools (and though this is especially true of secondary schools, the same thing occurs in Public Schools) the boy, once he has decided to concentrate on science, is cut off almost entirely from literary subjects. From the time when he takes the School Certificate Examination until the end of his university career the knowledge he acquires of history or English or

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similar subjects is often negligible. Such teaching as there is on these lines is too often valueless, because underlying it is the feeling on the part of the boy that it is a waste of time, and on the part of the master that he is pursuing a vain attempt in the meagre time at his disposal to smear a little "culture" over minds essentially philistine, with whose main study he has no sympathy. The vast majority of science students from the age of 16 onwards are taught nothing that will enable them to understand the philosophy of science, or of the historical and political background against which their scientific work should be seen. The complaints that such scientists are "narrow" and "uncultured", though often grossly exaggerated and based on wrong criteria of "breadth" and "culture", nevertheless have a basis of truth. Those who are loudest in emphasising this division between humane and non-humane studies, however, are themselves perpetuating the very condition they profess to deplore.

This unfortunate state of affairs is shown most clearly at the universities, where those whose studies have been concerned with philosophy and politics, with a view to administrative positions, are left in ignorance of the scientific and technical forces which are moulding the society they wish to serve. The scientists meanwhile, as far as their formal education goes, are left in ignorance of the rudiments of political, historical, and social knowledge. Here we are in touch with one of the deepest problems of present-day education, the need for unification, for building some bridge across the gulf which separates literary and scientific studies. This is the point which Professor Whitehead stresses in a fine passage: "No human being can attain to anything but a fragmentary training of his capacities. There are, however, three main roads along which we can proceed with good hope of advancing towards the best balance of intellect and character: these are the way of literary culture, the way of scientific culture, the way of technical culture. No one of these methods can be exclusively followed without grave loss of intellectual activity and character. But a mere mechanical mixture of the three curricula will produce bad results in the shape of scraps of information never interconnected or utilised. We have already noted as one of the strong points of the traditional literary culture that all its parts are co-ordinated. The problem of education is to retain the dominant emphasis, whether literary, scientific or technical, and without loss of co-ordination, to infuse into each way of education something of the other two."

THE SPENS REPORT

It is partially towards this ideal of a greater unification of our education that the Spens Report on Secondary Education (1939) is directed. In many ways this represents a step forward in educational thought. It seems generous and sympathetic towards the position of science in secondary education, and shows a grasp of the needs of the subject both as regards curriculum and method.

The more general problem of satisfying the needs of a society based increasingly on applied science is faced by the heroic expedient of suggesting the creation of a new kind of school, the Technical High School. In its desire to break down the barrier that it sees between academic and technical education it concedes both too much and too little. Since it is widely felt that academic education has become sterile, there is a tendency in modern educational thought, a tendency to which the Spens Report gives support, to disparage the supreme value of intellectual activity, and to raise the status of purely technical and even of craft studies. Thus the Report seeks for an equality, at any rate in principle, between Technical High Schools and the Grammar Schools. Nevertheless, it is suggested that the upper age limit of the Technical High Schools should in general be 16. When this is put against the great importance that the Spens Committee rightly ascribes to the sixth form in Grammar Schools it will be seen that any idea of parity between the two types of school will be illusory in practice. It is more than doubtful whether such a parity would be educationally right. There could be no doubt as to which type of school would provide the recruiting ground for administrators. It would be the Grammar Schools; and in the Grammar Schools, in spite of provision for advanced courses in science, the bias for the most able boys is still linguistic.

The proposed time allotment for science is actually lower than that now given in many schools. For those taking a third language from the age of 14 (a form of pre-certificate specialisation that is significantly allowed), 93 term periods are allowed for mathematics and science together during the whole of the pre-certificate years. In some courses the suggested allotment is even less. This deficiency is to be made up in the new Technical High School, where science is to be "the core and inspiration of the education" and will receive (together with mathematics) 8 hours a week. The science in these schools is to be of an eminently "realistic" type, closely related to the actual needs of industry. There can be no doubt that here science specialisation is associated with lack of opportunities of broad education beyond the age of 16, with a lowe status (however much the Committee may deplore this), and with a segregation from the cultural influences and opportunities for self-government provided by the sixth form of the Grammar School. The old division is therefore still present and is even accentuated in the Spens Report, and it will not be made less by attempting to lower the status of intellectual studies down to the technical level. Towards the better education of the technician the Spens Report makes a valuable contribution. Its attitude towards science teaching for those pupils most likely to proceed through the Grammar Schools to the universities and into administrative and professional positions of responsibility is far less satisfactory. (A full criticism of the Spens Report from the standpoint of the science teacher will be found in the *School Science Review*, December 1939.)

SOCIAL IDEALISM IN EDUCATION; THE CONTRIBUTION OF SCIENCE

The effects of the division in our education between "culture" and science go deeper than the mere creation of a barrier of ignorance between educated men and scientific social action. The secondary education of the nineteenth century, under the influence of Arnold and others like him, was very definitely education for social endeavour. He infused a new idealism into the Public Schools, and this idealism was adapted to the contemporary society. It was based on Christianity and on classical culture, and it was successful because it was possible, in a time of expanding liberal capitalism, to see the relevance of what was being learned at school for the needs of the world. There was ample scope for humanitarian activity, combined with the ideals of patriotic leadership which the Public Schools inculcated. At its best this kind of education produced a real sense of social responsibility; at its worst an authoritarian application of the prefect system to adult life. The relevance of present-day education to the needs of the world is no longer so clear. The technical background of society has changed much faster than education has changed its content and its methods. The gap between education and life, actually present in Arnold's day, has now widened and has produced the sense of unreality that is experienced so keenly by many of the senior boys in schools and by students at Universities. This unreality does not of course arise simply from the position of science in the schools. The position of science is, however, involved in the larger problem, for when education is out of touch with the dominant trend of advancing knowledge the social conscience which it may quicken will be rendered ineffective. As Professor Clarke says: "One cannot help feeling that the whole national attitude to science needs to undergo drastic revision. Science has to be thought of not as a mysterious and highly complex cult, pursued by highly specialised 'scientists'; not as a many-sided magician producing wonders for the populace and profits for the enterprising; nor yet as a technical necessity of modern life for which, however reluctantly, any self-respecting school must make some provision. It is rather modern life itself in one of its most fundamental aspects, and therefore an essential basis of a modern education for everybody. Not the whole basis by any means, but an essential part of the whole."

By their steady refusal or inability hitherto to grasp the social significance of the changes in a civilisation rapidly developing the technique of science, the schools have frustrated themselves and the society which looks to them for moral and intellectual leadership. Despite the growth of science teaching this maladjustment of our educational system and our social needs is manifestly one of our most pressing problems. This lack of adjustment has reacted adversely on the "humane" subjects themselves. Because they are out of touch with the new world, they tend to look back wistfully, instead of looking forward hopefully. The study of the classics has too often become a barren textual game rather than a stimulating adventure. The study of philosophy has become a sterile analysis, unrelated to actual life in a real world.

This must inevitably be so when the teachers refuse to be fully aware of an intellectual movement already in being. It was not so in Greece nor at the Renaissance. Then learning was an adventure in a young world in which much might be done. The realisation that this is still more true to-day would infuse a new sense of responsibility and purpose into our education and thence into every field of social and intellectual endeavour.

CHAPTER III

THE CONTENT OF SCIENCE COURSES

THE AIMS OF SCIENCE TEACHING

IF the foregoing diagnosis is correct, the present faulty relationship between science and social needs is primarily an educational problem, and the first steps to its solution must be taken in the schools and universities.

It is not, of course, suggested for a moment that the cure of our major social ills, or even our major educational difficulties, lies entirely in a number of reforms, however radical, in science teaching. It is, however, contended that since the roots of social progress lie in the schools, a pre-requisite of fruitful social readjustment is the making available of the knowledge which will make such readjustment possible. We hold, therefore, that every child must receive an education containing science sufficient for the duties of his citizenship. Such an education should ideally be adequate both as regards content and as regards the training in scientific method which it will give. It must place at the disposal of the future citizen sufficient factual knowledge to enable him to understand the forces which are forming his world and the potentialities for good and evil which science is opening up. Secondly, it must attempt to inculcate a scientific attitude that shall include a respect for objective truth, a willingness to experiment wherever experiment is possible in the solution of a problem, clearness of reasoning, and a conscious effort to overcome prejudice and personal bias. Professor Bernal summarises the aims of science teaching in his statement: "The chief claim for the use of science in education is that it teaches a child something about the actual universe in which he is living in making him acquainted with the results of scientific discovery, and at the same time teaches him how to think logically and inductively by studying scientific method." He goes on to say: "A certain limited success has been reached in the first of these aims but practically none at all in the second."

In addition to the teaching of some science with these ends in view we must also consider anew the education of those persons who are going to be science specialists. From these will be recruited future generations of science teachers, and in addition to following various other professions, a number of them will become research workers, an increase in whose numbers is one of the vital requirements of the future. There are thus a number of distinct problems to be faced in considering in detail the development of scientific education. In general these problems fall into two classes—content and presentation. In practice the two questions: "What is to be taught?" and "How is it to be taught so that the scientific method is instilled?" are closely interconnected. Some separation is, however, possible, and the first task is to discuss the factual content of our science courses.

The General Course

It is no easy task to define with any precision the factual limits of the scientific education that our potential citizens should receive. There is, in the first place, the inherent difficulty of selecting from the great mass of available knowledge those facts of special and fundamental importance and those of particular applicability to the everyday world, which can be presented in the time available. There is also the very genuine difficulty, which is not always faced even by the most enlightened critics of our education, that an appreciation of many of the most fertile discoveries demands knowledge that is simply too difficult for the majority of boys and girls. Thirdly, we are not in our education dealing with a homogeneous group of individuals with common ends and capacities. Our teaching as, in fact, to consider boys and girls who finish eir formal education at 14½, or at 16, or at 18, as well as that minority who, after remaining at school till 18, then proceed to further education at the university.

Of the more highly educated groups, some pursue their scientific studies to a relatively high level because of their professional requirements, while the majority do not. It can be seen, therefore, that the problem of framing a minimum syllabus is, even from the purely factual point of view, a complex one. In the following pages we are concerned with the minimum factual knowledge that should ideally be possessed by all citizens, however that knowledge is obtained, whether in secondary school, senior school, or by adult classes. In practice we are concerned mainly with what is at present possible with the majority of secondary school pupils. The less academically gifted pupil of the senior or other post-primary school will get something from parts of such a course, while some of it may be beyond him. This is a matter for selection by the teachers concerned.

THE QUESTION OF "GENERAL SCIENCE"

Until a few years ago, the sciences were divided, for teaching purposes, into almost water-tight compartments. Physics, Chemistry and Biology (in so far as the last of the three was taught at were treated as wholly separate subjects, tho a certain overlap was impossible to avoid. The modern tendency (as represented, for example, in the Spens Report) is to break down this division. In the early stages of education, at any rate, it is widely felt that scientific subjects should be fused together to form one subject, "general science". Thus the most comprehensive and most satisfactory syllabus of school science yet devised (that of the Science Masters' Association) envisages a parallel teaching of the three main subjects in such a way that their unity is brought out. It is a substitution of the idea of science for that of the individual sciences. That such a general principle of unification should underlie the framing of what may be called the citizen's minimum course is certainly advisable. Any hard and fast division is artificial. Nevertheless, it is often convenient to classify the facts taught under the usual subject headings of physics, chemistry and biology. In some schools they will probably be most conveniently taught separately. Too much has been made, perhaps, of the name "general science". The fundamental points are that a wide range of scientific subjects should be taught, and that they should be taught in such a way as to emphasise the unity of the scientific approach to human problems.

At this point we may consider a fundamental objection to the whole technique of science teaching that is very frequently raised by educated men who have had little formal training in science. "Why", *they ask,* "*is it necessary for everyone to* learn the 'grammar' of science at all? It consists of a very large number of facts, some of which may conceivably be of practical importance to some people, but the majority of which have not even that justification. Would it not be better to concentrate simply on teaching scientific method or the history of science to older pupils, and leave the detailed factual basis purely to specialists?" This criticism is of such frequent occurrence that some answer must be given to it, particularly as it does provide some indication of the criteria on which we should select the particular facts to be included *in our basic science course.*

It must be admitted that it is not easy to justify in concrete terms the teaching of a large number of the elementary facts of science. The same is true, however, of many of the other subjects taught in schools. The relevance of these facts is seen not when they are considered in isolation but when they are viewed as part of a body of knowledge. In so far as virtue is claimed (as sometimes it still is) for the mere process of learning, the basic facts of science share that virtue with those of other subjects. As regards their actual contact with the experience of the pupil, even the most elementary stages have a very definite advantage over the facts memorised at corresponding levels in many other subjects. There is no doubt that boys and girls between the ages of 10 and 14 have a very fresh and vivid interest in the external world, and the study of science is in a particularly favoured position as regards the capturing and capitalising of their interest at this stage of development. For all children, whether they intend to be scientists or not, a general science course provides a body of knowledge which can be made of living interest and which further provides an easy transition between the worlds of thinking and doing. It is usually found that the most thoroughgoing critics of the function of general science in education were themselves taught some science in an arid and unattractive form at too late a stage in their mental development, when the forces of naïve and widespread curiosity were no longer active.

To those critics who contend that the amount of scientific knowledge gained through an elementary general science course is far too small to be of any use to the future administrator, who will always, as now, have to call in his experts, the following answer can be made. The administrator or business man who has received some general education in science will in fact be more anxious and willing to call upon the advice of experts than one who knows nothing of science. The mere smattering of science that remains to him, after perhaps thirty years, will make him more aware of those fields in which the advice of the expert should be sought and his judgment accepted. Also it must not be forgotten that even an acquaintance with the grammar of science will make it possible to ask the expert the right questions and to form a truer judgment on his answers; this surely is better than to regard the scientific and technical sides of the problems of government as closed and semi-magical fields of esoteric knowledge.

There are two possible answers to the suggestion that science teaching to the non-specialist should consist solely of the history and method of science and should ignore the factual side. The first is that it is, in fact, almost impossible to convey the significance of these most valuable aspects of the study of science without some knowledge of the facts with which the history or the method deals. Even if we ignore altogether the other educational values of learning the rudiments, such as their general interest and their everyday utility, it must still be admitted that these rudiments provide the key without which the lives and achievements of a Faraday or a Curie lose half their interest and most of their significance. Finally, if science teaching were weakened in this way, if it merely concerned itself at a late stage in the school curriculum with an exposition of "scientific method" considered *in vacuo*, it could not hope to be taken seriously by the pupils. For the importance of any study to be grasped, a reasonable amount of time and energy must be spent on it; its importance for society must be reflected by its importance as a school subject. Such arguments then against a universal education in the actual facts of science, plausible as they may seem, must be rejected if we are to emerge from our present educational difficulties.

BASIC PRINCIPLES FOR BUILDING A CURRICULUM

In selecting the facts to be taught under the name of "general science" or under the headings of separate subjects, two principles stand out as of the greatest importance. Firstly, facts and examples must be chosen with as direct a contact as possible with everyday life. They must not be meaningless fragments of knowledge without apparent relevance to life and thought.

This is an obvious principle, but it is often violated through the unconscious effects of habits. In the teaching of elementary chemistry, for instance, the beginner is sometimes introduced during the first few weeks of the course to substances such as sodium, alkaline pyrogallol and phosphorus, with which he is completely unfamiliar. It is not, of course, always possible to avoid this unfamiliarity. We must, however, always remember the danger of raising a barrier of unreality between what we teach and the everyday world, and of losing the interest of the child by suggesting that science deals only with the unfamiliar and the remote.

Secondly, the facts taught must be relevant to the solution of some major problem, and that relevance must be made clear to the pupils to the utmost limit of their comprehension at their age. We must avoid the teaching of snippets of science, however closely related to everyday life such fragments may be. We have already stated what we consider to be some of the major problems of science—the conquest of power, of distance, of substances and of disease. It is under such headings as these that the basic facts of science should as far as possible be presented. It will not of course be possible to avoid teaching some facts of little apparent significance in themselves, since some of these are necessary for further steps in knowledge. In general we may say, however, that the criteria of connection with life, and relevance for the understanding of some important general principle, should be applied to every fact which is included in a school science course. It is in the light of these principles that we should, in the most critical spirit, scrutinise constantly the factual content of our teaching.

THE SYLLABUS OF THE SCIENCE MASTERS' ASSOCIATION

By far the most satisfactory attempt to frame a school science course that is adequate from the factual point of view is that of the General Science Sub-Committee of the Science Masters' Association. It is of interest to consider the method by which this course was evolved. In order to relate the facts taught to the interests of the pupils, three members of the Committee drew up a list of things boys or girls want to know and questions they want answered, giving preference to those topics which seemed to play a greater part in the pupils' lives. Meanwhile, three others selected what they considered to be the fundamental scientific ideas, and the subject-matter which best exemplified them. The resulting lists showed a considerable amount of common material, and this formed the basis of the syllabus, which was then worked out in detail so that the work for each week of the course was clearly visualised. First a minimum syllabus was published for the many schools where at present there are available only four periods a week for four years. Two years later an extended syllabus was produced for use in schools with a more adequate time allowance. The complete course covers the elements of chemistry, physics and biology with some astronomy and geology, and strong emphasis is laid throughout on practical applications.

With this Science Masters' Association syllabus we should, in general, most cordially agree. There are points of detail where perhaps the dead hand of traditional content shows its influence, but these are of small importance. The general impression on reading the syllabus is that here is an admirable and successful attempt at defining the broad limits of what science should be known by every fully educated citizen. One important question does, however, arise. The time given for the complete course suggests either that the detail envisaged is too great or that too much time is to be spent on practical work. More will be said on this point later. What is for the moment important is that, in our view, ample time is available for the inclusion of the special topics such as the properties of plastics, colloids and their uses, wave-motion, and the development of the chemical and electrical industries, which are suggested by the framers of the syllabus but are omitted from the minimum course.

Other Criticisms of the Factual Content of School Science

What has been said above on this difficult question of factual content may well be considered in the light of Professor Bernal's comments on science teaching in his *The Social Function of Science*. His criticisms are diametrically opposed to those of the critics already mentioned. Whereas they consider that school science tries to teach too much, he is concerned that it should teach so little. After a plea for an earlier start in science he goes on to say: "Now physics and chemistry as required for university entrance or school certificate has been worked into one of the most repulsive routines imaginable. A vicious circle has been established between the schools and the universities by which neither can alter the curriculum because of the objections of the other. Science is taught so that a fraction of those taught can go to the universities in order to learn to teach it in just such a way to future generations. It is true that science masters in schools have devoted an enormous amount of care and ingenuity to making the curriculum attractive, but for every boy that it attracts there must be two or three that it puts off science for ever. It is unfortunately true that those parts of science most suitable for examination subjects are the metrical parts of physics and chemistry (the attractions between magnets, the combining weights of sodium bicarbonate and sulphuric acid), and these are at the same time the most troublesome to the lazy and unmathematical boy, and the most exasperating to those who are really keen on science and want to get on to those parts of the subject where something new and interesting is being found out. There is little, in fact, in school physics and chemistry that was not known a hundred years ago, and much that was known three hundred years ago. Science masters are, of course, aware of this state of affairs and have been trying in the face of apathy and obscurantism to set their house in order. A recent report prepared by the Science Masters' Association on the teaching of general science goes far to meet many of the criticisms that have been made here.... This (i.e. the syllabus), though it makes a definite advance, lacks comprehensiveness and modernity. There is a good biological section, but nothing on astronomy or geology. Of the ten sections into which each year in physics is divided, the first two years contain only one fact each, and the third only two facts discovered in the 19th century. Only in the last year does the outlook become more modern, but even then nothing later than 1890 is introduced. X-rays, wireless and electrons are not so much as mentioned. The chemistry is worse; the whole course contains nothing not known in 1810. The whole of organic chemistry, without which biology is incomprehensible, is omitted, and modern ideas on the structure of matter never even hinted at. Nevertheless, if the spirit in which this approach has been made is maintained, it is still possible to hope for a living system of school science teaching."

We have quoted Professor Bernal's criticisms at considerable length, because coming from a source as important as *The Social Function of Science* they command special respect. There is much in them that is true. Some of the points have been met in the Science Masters' Association revised General Science course, in which, for example, astronomy and geology find a place. But the criticism that the factual content of our science teaching lacks modernity remains unanswered. This actually constitutes a very real difficulty. One suspects that Professor Bernal is overestimating altogether the capacity of most boys and girls between the ages of 12 and 16. The plain fact is that much of the modern work in physics and chemistry is simply too difficult for them. Again, no one would wish to omit the whole of organic chemistry, but here the same difficulty presents itself. The subject very rapidly becomes too complex for the ordinary pupil. In so far as there is a solution to the problem raised by this criticism it probably lies in an entirely descriptive and even consciously superficial approach to these particular subjects.

A similar kind of criticism, though this time merely an implied one, is contained in another important book, Professor Hogben's *Science for the Citizen*. The factual content included in this book is presumably that which Professor Hogben thinks the ordinary educated man should possess. But here again, though there is in the work a good deal of the greatest value to which reference will be made later, one feels that the capacity of the ordinary person is being enormously exaggerated. No general science course could, or should, seek to cover the ground of *Science for the Citizen*. If we look at some of the examples on the various chapters, we find such questions as "Write down the compounds which can have the following formulae with their properties and methods of preparation: C_2H_4NOCl, C_3H_5CNO"; or "With the aid of three consecutive issues of Whitaker tabulate the R.A. of Venus and Mars for a sufficient period to determine the sidereal period of each planet, and determine the relative breadth of their heliocentric orbits, assuming that they are of the circular form". Such questions demonstrate that with all the other brilliancies of the book, Professor Hogben has not satisfactorily solved the problems of factual content. The minimum for the ordinary man is necessarily much less than Hogben demands. We must beware in framing our new courses of fastening on our schools a new tyranny that demands an impossibly high standard of factual knowledge in science, while at the same time we must avoid the under-estimation of the range of the pupil's needs and interest that at present occurs.

General Science in the Sixth Form

The Science Masters' Association syllabus is a four-year one, covering the years from 13 to 16, and our discussion has so far been mainly concerned with that age group. It is vital, however, that some provision should be made for the continuance of general scientific education beyond that level. In many schools the last two or three years are, at present, spent in fairly rigid specialisation. This means that the able non-scientist probably receives no further science teaching after School Certificate, and the able science specialist is prepared for Higher Certificate or a University Scholarship with no recognition of broader issues in his science work. The good done by a rational general science course may thus, instead of being strengthened and amplified by the further period at school, be undone and forgotten. This is particularly lamentable, as it is precisely these students who will join the administrators and leaders of the next generation. It is also at this stage, as has already been said, that the pupil will be intelligent enough, and old enough, to see historical and social relationships. It is, therefore, essential that there should be a fifth and even a sixth year of general science of a very broad kind, that shall be taken both by the boy specialising in classics, or history, or modern languages, and also (and this seems an essential point) by those who are science specialists. The precise content of such a course will depend very much on the inclinations of the individual teacher. In general terms it should include some of the following topics. In the first place some consideration of the history of scientific discovery must be included. This will comprise both an account of the historical background of scientific discovery and of its social repercussions, and also give some account of the relation between science and the general thought of mankind, especially in philosophy. This continuation of the general science course should also contain more biology than was possible at the earlier stage. Biological topics with a marked social trend, such as the facts and theories of heredity, the measurement of intelligence and the problems of population, should be stressed. It is at this stage of the science course, also, that some brief survey of modern physics might well be attempted. Such a survey should include atomic structure and radioactivity, but the wisdom or possibility of making such a subject as relativity part of the ordinary scientific equipment may be very much doubted, in spite of the numerous attempts at popularisation in this field. On the more directly practical side, a number of subjects such as science and agriculture, or science and building, might form the basis of several lectures. Finally, it is at this stage of the general science course that scientific method may be dealt with as a special subject. But whatever the particular subjects emphasised by individual masters, one point is fundamental. If an emphasis on the idea of social purpose is found too difficult to realise explicitly at an earlier stage, there can be no excuse for not including it at the later. The whole of the one or two year's post-School-Certificate general science course must be infused with the ideal of scientific humanism.

THE CONTENT OF SPECIALIST SCIENCE COURSES

Those who see in the wider development of science in the community and in education a necessary social advance are faced with a very real difficulty when considering the education of those who are intending to take up careers for which advanced work in science is required. On the one hand, it is essential that such specialists should reach a high standard in their particular subjects if research is to continue and to develop as it should. On the other hand, time must be found, as at present it frequently is not found, for the fuller education of these students by teaching them something of the historical background and philosophy of their scientific studies. This problem arises both in the schools during the post-School-Certificate stage and subsequently in the universities.

Post-School-Certificate Courses

There is no doubt that the training at present given in many schools to pupils preparing for Higher Certificate and University Scholarship Examinations is inadequate as an education. It is at this stage that the foundations are laid for a narrow view of the nature and functions of science, and an indifference allowed to remain as to its social implications. We suggest that every Higher Certificate student ought to spend five or six periods a week on subjects other than science and the foreign language, usually German, necessary for his scientific studies. How these periods are spent must depend partly on the school and partly on the interests of the master who takes them. He may prefer to call the work "English" or "Civics"; what is essential is that it shall stimulate the pupils to a wider interest in fields of knowledge outside their own. In some way the problems of citizenship and the light that the study of history throws on their science must be made real to them; whether it is done by reading Plato, or by the study of current affairs, is a matter for the teacher to decide.

It will at once be objected by some teachers of science that such a programme will simply not leave enough time for preparing the pupils for the Higher Certificate Examination. There is substance in this objection in so far as some schools make too great a fetish of a high standard in this examination. Partly owing to the award of State Scholarships on its results it has acquired a false and competitive value, and it is disturbing to find that some pupils take this examination two or even three times, when they have passed quite creditably at the first attempt. There is no doubt that the examination could be passed by quite ordinary pupils, who spent rather less than the present allowance of time on their specialist studies, if the teaching technique at this higher stage were modified. At the Higher Certificate stage more than at any other in our scientific education pupils are encouraged to note down and memorise vast numbers of isolated facts for which any competent research scientist would always go to a reference book. At this stage, too, a great deal of routine practical work of very doubtful value is often carried out; to this practice we shall direct attention in the next chapter. The dreary performance of meaningless qualitative analyses in chemistry is a case in point.

The questions set by certain of the Higher Certificate Examining Boards suggest that many teachers are lagging behind the more progressive examiners in their interpretation of what constitutes a desirable factual content. We must learn to regard the facts at this stage as tools rather than as ends in themselves; as tools for the solution of particular scientific problems.

This attitude is on the whole well exemplified by many questions set in University Entrance Scholarship Examinations. Here the standard is too high for the average Higher Certificate pupil, but the emphasis is properly laid on scientific principles rather than on an immense factual knowledge. University Entrance Scholarships also, by means of a compulsory "General Paper", point the way to a recognition of the claims of higher education in other than the subjects in which a pupil is specialising. The present papers, however, though admirable in intention, are not usually completely satisfactory. Their style is often too "clever" for the boy of 17 or 18, and they tend to look for individual "outside interests", such as art and music, rather than to test the quality of the general education received. If, however, papers of the same kind, though more defined in scope, were set to science candidates in the Higher Certificate Examinations, it would mark a step forward in the co-ordination of the higher education of specialists. In assessing the worth of the answers to such questions it will be important for the examiners to bear in mind the importance of the home and school background of the individual candidate so that some allowance can be made for their varying performances. A secondary schoolboy from a poor or uncultured home is obviously at a grave disadvantage, and his headmaster should be invited to supply information which will enable the examiner to distinguish the boy's actual performance from the potentialities which he might be expected to develop in the university environment.

It is obvious from what has already been said that we look forward to the time in the near future when candidates for University Entrance Scholarships in literary and other subjects will be expected to show that they have some acquaintance with science, and in particular with those aspects of science which are transforming the modern world. We have also urged that students who are candidates for scholarships in science in these examinations should attend at school the post-School-Certificate classes in which parts of the history, method and effects of science are discussed.

Mention has also been made of the very high standard of some entrance scholarships. Experience shows that a boy can study his science intensively for two or three years after passing the School Certificate standard and absorb a vast number of facts without thereby acquiring a scientific outlook. Few teachers of science will not have met the boy who trusts uncritically every word of his textbook, and looks upon his laboratory work merely as a set of exercises designed to satisfy examiners. The same type of boy is also apt to feel that any time given to subjects which are not directly connected with his scholarship examination is wasted. For this attitude the boy is, of course, not entirely to blame, since to many the scholarship is the only path to the university, and in the examination an extremely high standard is expected both in factual knowledge and in intellectual attainment. So long as the standard of entrance scholarship questions approximates to that of a degree examination, we must expect that boys who know that their future depends so much on the grant of a scholarship will be unwilling to give time to any subject in which they will not be examined. If, however, the range of factual knowledge could be diminished by the university authorities concerned, it would be reasonable to insist on a wider distribution of post-School-Certificate studies so that the boy's outlook could be enlarged.

Science Specialists at the University

The work done at the university by undergraduates who are reading for Honours in Science consists usually of two years spent on three or four science subjects, followed by a year's more advanced work in one of them, or of three years' work on one subject with additional courses of lectures on allied subjects.

These courses, designed to train chemists, physicists, biologists or doctors, though very successful in their immediate object, leave out at present many of the aspects of science which seem to us to have great value to the citizen. If scientists are to play the increasing part in the life of the community in the way that is being envisaged by many people to-day, there is no doubt that the kind of education which they receive at the university must be most carefully scrutinised. Probably a considerable measure of reform is necessary.

University courses in science are performing several functions. They provide the final stages in the training of the future research scientist for academic, industrial and government work; their tone is therefore of vital importance for the development of the professional scientific worker's attitude towards both his work and the community. Secondly, the scientifically trained man or woman who is to become an administrator will complete his or her education at the university. Finally, a large number of the science students at the university will become teachers, and their attitude towards the whole problem of the nature and purpose of scientific education will be conditioned by their specialist university training. Now the most fundamental criticism that is made against those who have received a scientific education is that they become narrow specialists, the implication being that a scientific training is more narrowing than any other. It is suggested in particular that the education of future teachers is too specialised. The Spens Report, for example, says: "The present university requirements in the way of an advanced knowledge of mathematical and experimental physics or of chemistry are now becoming so highly specialised for those who intend to use those subjects in the research and design departments of modern industrial concerns that it is very doubtful whether such courses can be made suitable at the same time for the intending science teacher unless he contemplates only Sixth Form work." The remedy proposed is a wider education in science at the university, and in suggesting this the Spens Report is approving a tendency already at work in the universities. "We are, therefore, of the opinion that degree-giving courses which involve the knowledge of at least three sciences, such as already exist at certain universities, ought to exist more widely, since it is likely that there will be an effective demand for such courses if our recommendations are adopted."

Superficially there is a good deal to be said for the proposal of the Spens Committee, but it is a proposal full of danger if science is to take its rightful place in education. The proposal ignores the real core of the problem. Our scientific education is at fault not mainly because the interests of our scientists are too narrowly directed within the field of science itself, but because they do not include the wider implications of science as a whole. For example, the education of our professional physicists is not at fault because they know no chemistry beyond the Higher Certificate standard, but because their physical studies lack a historical and philosophical background. A science course embracing physics, chemistry and biology is certainly justified up to the university entrance level, and here there is a field for reform, but if this breadth is introduced into the work at the university the cure may be worse than the disease. The extent of the purely scientific ground to be covered will tend to turn the student's interest even more exclusively towards his own studies. The degree courses in some universities are too short as it is. If in two years an undergraduate has to reach even a modified degree standard in three subjects, he will have little inducement to widen his interests, or to pursue those leisure activities which are among the most important contributions of the university stage to education.

Further, such a wide course at the university is unnecessary from the teaching point of view. A student who has pursued a subject as far as university scholarship standard is in practice competent to teach it as a subsidiary subject to his main science. He is far more likely to teach it well if his university course has taken him far enough in some one subject to understand something of the atmosphere of research and of really advanced scientific thought.

The suggestion raises another important point. Would it not tend to segregate intending teachers from the other university science students? Such an effect would be deplorable. Students of high ability will tend to commit themselves to the more specialised courses leading to a year or two of research. The intending teacher will be shut off from contact with the living and growing aspect of his subjects. Reform should surely take place in the opposite direction; the delaying of the decision to undertake teaching as a career, and the bringing of all science students into touch with that research atmosphere which is one of the most important though imponderable elements of the contribution of the university. It may be necessary in the future to lengthen university courses with this end in view and with the further object of avoiding overpressure at a time when leisure is essential for wide intellectual development.

If the broadening of the specialist science student's approach is not to be brought about by widening the variety of his scientific studies, what then is the solution? In addition to the lengthening of university courses already referred to, the greatest step forward would seem to lie in introducing courses of lectures for all science students in the history of science and on philosophy and related subjects. We suggest that many university graduates in science lack any knowledge of the philosophy and history of their subject and have not been given sufficient opportunity of obtaining such knowledge.

The lack of this acquaintance with the intellectual background of his subject is especially a handicap to the graduate who becomes a teacher of science in a school. He tends to teach, for some years at least, as he has himself been taught; thus his science teaching will be unduly narrow in outlook. At a time when he should have been getting a vision of the ends as well as the means of his science, the opportunities of acquiring a wider outlook have not been brought to his notice.

The vast fields of knowledge which have to be surveyed in a present-day university course make it difficult for the average undergraduate to give much time to work of this sort. It seems, however, very desirable that the university authorities should offer short courses of lectures on the history and philosophy of science, and that college tutors should recommend their pupils to attend them and give their pupils practice in writing essays on broad topics which would enable them to clarify their ideas by writing about the problems and discussing them. The time so used need not be great, for once the student has been brought in thorough contact with the ideas, his own interests should make him read and think about the subject.

The problem of finding the right lecturer for such university courses is not an easy one. Unless he is able to fire the imaginations of his hearers, the numbers who attend will rightly fall off rapidly during a university term. Some attempts have already been made to broaden the scientist's equipment in this way. It would be wrong to stereotype the content of such courses; as with similar studies in schools, the teachers must make the courses. It can scarcely be doubted, however, that such work would have profound effects both upon future teachers and research workers.

Some such reform must be indeed an essential part of the general reforms in education which are pre-requisites of a proper absorption of science into our social pattern.

CHAPTER IV

THE PROBLEMS OF PRESENTATION

IF the primary function of science teaching is to ensure that every educated citizen has learned a sufficient number of scientific facts to enable him to understand his environment, that is by no means its only task. It is no less essential that a scientific attitude of mind shall be created, and also that the facts shall be seen in their appropriate social relationships. These and other subsidiary educational functions are partly questions of content, but they also involve problems of teaching technique. It is because our present education most clearly fails, not so much in teaching the facts as in inculcating the scientific spirit and in making clear the social implications of science, that the problems of presentation must now be considered in some detail.

The presentation of the facts of science differs from that of most other subjects in the possibility of the pupil actually performing experiments for himself. In the early days of science in schools (that is to say until twenty or thirty years ago) this side of the work was always hampered by grossly inadequate laboratory accommodation and shortage of apparatus. In some schools this starving of a necessary part of scientific work is still to be found. But in general it is now realised that practical work is essential for a wide variety of reasons. The early neglect of this side of school science has, however, produced evils which still persist. The reaction against a technique of teaching robbed of a good deal of its value by the absence of laboratory work has led to an over-insistence on the value of such work for its own sake. This too often leads to an aimless repetition of stereotyped experiments. It is unfortunately true that the exact functions of practical work are not always consciously present in the minds of teachers, and hence science teaching in schools tends to fall into the routine of a lecture followed by a practical that has too little relation to the real needs of the pupil, or to the real aims of a scientific education. Far too many experiments carried out are bad experiments, in the sense that they are pointless or obscure instead of helping to clarify fundamental issues; and much valuable time is wasted on the dreary performance of operations with very little educational purpose. There is no field of science teaching in which it is more necessary for a teacher constantly to ask himself for a clear and precise definition of his aims. If those aims are kept clearly in mind then practical work may become what it should be—a constant and indispensable exemplification of the principles of scientific method, as well as a technique of assisting the memorisation of the factual content of the course. The following are some of the principles which we believe that laboratory work should embody.

THE FUNCTIONS OF PRACTICAL WORK

An experiment or demonstration is justified if it teaches accurate observation and clear description. Nothing is more characteristic of the unscientific mind than the inability to describe accurately a series of events, even of a very simple character. There is a great value, which is probably not sufficiently realised, in letting pupils perform simple experiments purely from this point of view, and then submitting their accounts to a rigorous critical examination, separating actual observation from unjustified inference, pointing out omissions (often, in practice, of a most glaring kind), and so on. The action of heat on various substances (e.g. starch or lead), the action of reagents upon unknown substances, the deposition of substances during the passage of an electric current through a liquid, the observation of a thermometer in water which is being heated up and allowed to boil away, are all suitable experiments for this kind of elementary observational training. The explanation of the observed facts may be given later, but initially the pupil's attention should be directed to the difficulty of being really accurate in the simplest account of his sense impressions.

Practical work has another value, in impressing important facts by personal observation. The vital factor here, as indeed in a great deal of practical work, is that the actual manipulation should not distract the pupil's attention from the real object of the experiment. Actually, a large number of the practicals usually done in school courses are ill-chosen from this point of view. They are bad because the pupil is so bewildered by adventitious difficulties that he is often completely unaware of why he is doing the experiment at all. Experiments such as the demonstration of increase in weight when substances are burnt, the reduction of oxides with carbon, and even perhaps the demonstration of the law of multiple proportions by reduction of copper oxides in coal gas, do, however, emphasise the important facts they illustrate, particularly if they are carried out in a research spirit, rather than as an "exercise for the student".

It must not be forgotten that practical work may inculcate definite manual skill. The value of such manual dexterity is, perhaps, difficult to define in precise terms, but is probably closely linked with deep constructive impulses, and those who have acquired it have no doubt of the satisfaction its exercise gives. Primarily its acquisition helps to bridge the gap in the pupil's mind between thinking and doing; and hence the devising and construction of an apparatus suited to a particular purpose, however simple, is a very profitable exercise. Practical work of this kind, of which simple glass-blowing is the obvious example, has the great advantage that it is popular and enjoyable. An important point that is frequently not realised is that technique is best taught as such. It saves much time if operations which will be very often repeated are demonstrated and practised at the beginning of a particular course. Such operations are the boring of corks, the use of a micrometer gauge, the accurate localisation of an optical image, or, in more advanced work, the recrystallisation of a substance. Some time devoted to the learning of such simple technique avoids the very real difficulty already mentioned that pupils are too often baffled through not having acquired reasonable skill in manipulation. Hence they cannot concentrate on the observations, nor appreciate the real purpose of the experiment.

A certain number of experiments must be performed in which success depends mainly upon an intelligent following of written directions. This is true of some chemical preparations; but actually the educational value of such "cookery" is not very high, and it is probable that too much of it is attempted. The attitude produced by the slavish following of instructions is, of course, a harmful and unscientific one.

PRACTICAL WORK AND SCIENTIFIC METHOD

Practical work should often be directed towards emphasising some particular aspect of the scientific method. An important characteristic of that method is the isolation of variables. This can be exemplified in such experiments as the investigation of the relation between the frequency of vibration, the length, the mass, and the tension of a stretched wire. Experiments of this kind only become of value if the method is clearly grasped by the pupil.

Two other very important principles of scientific method should be extensively illustrated in elementary practical work. The confirmation of facts by independent observers should be made the chief underlying justification for such tedious experiments as the determination of equivalent weights—experiments which should, in any case, be kept small in number, for they are often overdone. Every opportunity should also be taken of using team work in a class. Such an exercise as the plotting of a solubility curve by the whole class can be justified if this co-operative approach is emphasised.

A most important point to be borne constantly in mind is that wherever possible a research attitude should be inculcated through practical work. This is admittedly difficult in very elementary work, and teachers are often specially hampered here by difficulties due to large classes and lack of apparatus. But much can be done, even with quite young pupils, along the lines, say, of comparing the catalytic power of manganese dioxide with that of other powdered substances in the preparation of oxygen, where the method and apparatus would have to be devised, each different experiment being performed, perhaps, by two sets of workers, and the results of the whole class finally interpreted.

Lastly, some very few practical experiments may be done simply to win or keep interest, apart from any other value. The growing of crystals or of silicate gardens may be justified in this way. In general, purely spectacular experiments, in so far as they are done at all, are best reserved for demonstration, and the time of the individual pupil will thus be saved.

OVER-EMPHASIS ON QUANTITATIVE WORK

We have outlined above some of the considerations which, in our view, should determine the direction of practical work if it is to become significant in the pupil's mind and take its true place in his scientific training. We make no apology for being, perhaps, over-simple, because so much time is wasted in some schools in practical work which does little good, and may be positively harmful to the development of the scientific attitude. In chemistry, for example, a good deal of time is often spent in school courses on preparations, such as those of the oxides of nitrogen, which simply do not accomplish their object, which is presumably to fix certain facts in the pupil's memory. The manipulation is probably too difficult to be anything but a distraction at an early stage. Worse still is the tyranny of quantitative work in chemistry. Some quantitative work is, of course, necessary and valuable, particularly when it is associated with a clear idea of probable error. But in chemistry particularly, the mistaken idea that a study is only scientific in so far as it is quantitative, has led to a multiplication of experiments that are dull, involve no real element of discovery, and as usually performed give inaccurate results. Is it worth while, for instance, to determine many equivalent weights or several densities of gases, or to perform at an early stage a determination such as that of the percentage of carbon dioxide in calcium carbonate? The same objection applies also to many quantitative demonstrations. Dumas's experiment on the composition of water, the determination of the equivalent of carbon, and experiments on the volumetric composition of gases are all usually demonstrated in elementary school courses. Some of the last must be retained, but of the others it can be said that they occupy a great deal of time, and in general the results obtained by the teacher serve only to demonstrate that under no circumstances is chemical change governed by exact quantitative laws! Too many such demonstrations end with an apology for the result and a general air of mystery, sometimes associated with a blaming of the workman's tools.

In general, demonstrations should be short and simple, and designed to hammer home some point where a visual appeal is likely to be most effective. Long and complicated demonstrations, such as that of the lead-chamber process carried out in a glass flask, have, in fact, very little value apart from the attraction of the spectacular.

In concluding these remarks on experimental work we would emphasise the saving of time which can be accomplished by a thorough overhaul of the conventional demonstration and practical work. When it is suggested that great stress should be laid on scientific method or on the historical approach, it is often pointed out that time is simply not available if that dread entity, "the syllabus", is to be satisfied. In many cases this is true enough. The jettisoning of pointless practical hours and laboured demonstrations would, however, set time free for such teaching of the historical relations and methods of science, especially during the general education of all pupils, when the lack of time is most strongly felt. We suggest that once, say, in five years, every science teacher should think out exactly what he expects from each demonstration or laboratory experiment which he uses. The more time presses the more vital this becomes.

THE SCIENTIFIC ATTITUDE

Particular attention has been paid to these points of teaching technique, because they have such a special bearing on the very difficult problem of the teaching of the scientific attitude. It is in the attempt to find a solution to this problem that our scientific education most obviously fails. This failure arises from the fact that it is apparently an exceptionally difficult educational task to communicate this attitude, and to ensure that some transfer of training shall occur between the classroom or the laboratory and the everyday world. Although it is possible, and sometimes desirable, to devise definite courses in scientific method, it is quite certain that all science teaching must have in mind the inculcation of that method in addition to the teaching of facts. Many teachers will prefer to rely on the ordinary course to provide examples of the scientific attitude, and not to attempt the heavy task of devising a special course that shall be both interesting and comprehensible. In either case, however, the teacher must have the points he wishes to emphasise clear in his own mind, and he must be constantly on the look out both for examples in his ordinary science teaching, and for ways in which examples from everyday life can be brought home as illustrations.

The main points in the scientist's approach that need to be stressed in the school are the following. It is necessary, in the first place, for the scientist to observe and collect facts. In connection with this fundamental process there are any number of points for the educator to stress. He must try and show that the actual sense data presented to us are complicated by inessential and irrelevant observations, from which the relevant facts have to be extracted. The great difficulty of accurately observing and describing even the simplest phenomenon has got to be made clear by constant example. In an actual course which is to inculcate scientific method, time should be found for some exemplification of the way in which a single sense impression may be grossly misleading, e.g. in the optical illusion. The possible errors even of the trained observer should be discussed, and the limits of accuracy of any observation pointed out. Further, as regards this primary part of scientific method, an attitude of distrust for mere authority, and of cautious reliance on the fully ascertained fact, has to be instilled. Nothing, of course, is more destructive of the genuine scientific spirit than the exaggerated respect for the textbook which is present in so much teaching. Every teacher knows the question "Sir, is this right?" applied to the appearance of some experiment in progress, and it requires a definite and determined effort to eradicate the distrust of observed fact and the unquestioning acceptance of authority that is implied by such a question. On the other hand, of course, it is also necessary to make the pupil realise the value of confirmation by independent observers, and appreciate the fact that, if his observation differs from a well-authenticated result, the only course is to repeat and scrutinise his own work with all the care at his disposal. This attitude of distrust and scepticism, the desire to resort always to further observation and never to unsupported authority, is, of course, fundamental to the scientific spirit. It is, however, admittedly difficult to convey in actual teaching. Still more difficult, perhaps, are the subsequent stages of the scientific method. We must show how from sufficient facts a hypothesis emerges. Suitable topics for illustrating this process are the usual study of burning, for beginners, or the ionic theory, or the wave theory of light, for post-certificate pupils. The dangers of over-simplification, of formulating a general law from too few examples, must be pointed out. The repeated testing of the hypothesis by further observation, and the creation of a provisional law, are the next stages. The two great points to be stressed here are, first, that the failure of a long-held hypothesis to stand up to observation is in reality a triumph for science, since it constitutes an advance in the approximation to truth; secondly, that in forming or defending a hypothesis or law, all personal bias must be eliminated. In some way the pupil must be trained to look for his own prejudices, and to eliminate them. The practical teacher may well regard all this as too nebulous and remote from actual teaching practice. Yet it is vital that in one way or another it should be incorporated into our teaching. With advanced pupils it can be illustrated fairly easily. A piece of semi-original work for the boy who has, say, won a university scholarship, and has a term or two to fill in, raises the problems of scientific method in a relevant and personal form. If the piece of work is well chosen, the consultation of original papers and the repetition of their observations very rapidly inspires an appreciation of the difficulties of accurate observation, and at the same time removes once and for all any exaggerated respect for the mere authority of the printed word. This method on a simpler scale may well be tried with less advanced pupils by setting them a problem of their own to investigate over several weeks. But at present, at any rate, it is unfortunately not often applicable to the elementary stages with which we are primarily concerned, nor to the pupil of average intelligence. With these less advanced pupils, the same principles have to be driven home by constant exemplification in the everyday practical work, as has been indicated. The historical approach is also often of value. A fairly detailed account of the work, say, of Faraday should make the principles of scientific method come alive in the imagination.

The scientific method is, of course, simply one mode of logical thought; and training in it can be acquired not only in the science laboratory but in other ways. We can attempt it, for example, by analysis of the advertisement pages or even the leading article of the newspaper. Examples of this analysis as part of a training in logical thought are to be found in such books as Jepson's *Clear Thinking* or Stebbing's *Thinking to Some Purpose*. This is not science teaching as usually understood, but however such training appears—whether as Science, or English, or Civics—is of little importance, as long as it is given. The inculcation of due care in statement and in the use of words, and the necessity for honesty and precision in argument, is the essential task, whether it is labelled "scientific method" or not. The science teacher should, in fact, be prepared to choose his examples of scientific and unscientific approach from everyday life, even when the subjects involved are apparently not remotely scientific. This will be one of the ways in which we may hope to secure some transfer of training between the science classroom and the outside world.

SCIENCE IN ITS SOCIAL CONTEXT

We must now turn to what is, perhaps, the greatest defect in our present treatment of science in education. It has already been pointed out that our failure as citizens is not only in our inadequate knowledge, and in the inadequate pursuit of new knowledge. It is also in the inability to see that the discovery of scientific truth is a social activity, that has meaning only in relation to mankind. However full the factual content of our teaching may become, however clear we make the principles of the scientific attitude, we shall not have succeeded in our main task unless our pupils learn to see scientific knowledge in its social context.

This view of science as a social activity can colour the technique of our scientific education in making us more anxious to point out both the social results of scientific discoveries, and the social background that gave rise to them. In other words, our presentation of the factual content must have more relation to history than at present. Such history must, however, be carefully distinguished from what has too often passed as the history of science in the past. The potted lives of great scientists and the brief records of great discoveries have formed a lifeless part of science teaching because the facts have not been seen against the general background of great social forces. The history of science only becomes significant when it is interpreted in terms of the needs and conditions of real men and women.

That such an approach is possible has been shown by Professor Hogben among others. In his *Science for the Citizen* an attempt is made to show scientific discovery in its dual capacity as man's answer to certain social problems and as the creator of new ones. Thus astronomy is related to primitive agriculture and religion; the facts of heat are seen against the background of the Industrial Revolution, and so on. Professor Hogben's actual technique, like his factual content, is suited to an adult audience, and would make too great a demand on the intelligence and general background of most school children before the age of 16. But this method of approach, illustrating what Professor Hogben calls "scientific humanism", is undoubtedly one that constitutes a new challenge to the teachers in our schools.

The Historical Approach

To meet this challenge we must relate the broad historical background and the social results of scientific discoveries. This approach may be illustrated by the case of metallurgy. The elementary facts of this subject can be taught either as a series of chemical reactions, or as a connected story of man's progress in the use of new materials, and it is the latter which we would urge is the more truly educative. The effect of tools of copper on building technique should be pointed out, for example. The metallurgy of iron should be discussed not only as an example of the reduction of a particular metallic oxide, but as a development of man's control over substances. This development became revolutionary in its speed in the eighteenth century and interacted with many other inventions to bring about the sudden growth of our machine age. The actual developments in metallurgical technique should be treated not merely as chemical advances, but as chapters in social history. Thus we may point out in this context that in the century from 1740 to 1840 the production of iron in this country increased about eighty-fold. Behind this enormous increase lay various improvements in technique that can be explained in terms of pure chemistry—the use of coke in blast furnaces, Cort's puddling process for the manufacture of wrought iron, and the discovery of the advantages of a hot blast. The change was also connected with interactions between the iron industry and other forms of mechanical invention. The free use of iron led to the development of new engines, trip-hammers, and pumps which furnished a stronger blast, for example, which themselves were used for the production of the metal in greater quantity. It may also be pointed out that the development of these engines involved the further study of other scientific ideas, in heat and hydrostatics, for example. In dealing with a subject such as this the science teacher must be prepared to go to such sources as the work of the Hammonds (especially *The Rise of Modern Industry*) for facts and illustrations to make his teaching become relevant and alive. His class may then see, implied in the great increase in iron production, the transformation of an industry with all the changes which this involved in the lives of the workers.

Later developments in metallurgy, such as those of the steel alloys, connect up easily with everyday life, and the prospect for the future must not be forgotten. We should not be afraid to point out that the development of electrical processes and of light alloys should direct our hopes to a cleaner countryside, where industries do not have to be concentrated round the sources of coal and iron. It should be made clear that the occurrence of the grime of smoke-blackened cities is not an inseparable accompaniment of scientific discovery, nor one in which we must acquiesce.

This is but one example of the social development of a particular topic. Many other examples suggest themselves. The chemistry of coal gas can be linked up with the rise of chemical industry as a whole; Boyle's law, and the investigation of the general properties of gases, with the need for pumping out mines, as coal-mining became important; the chemistry of food with the whole question of a minimum diet.

Some of the objections to this kind of outlook in science teaching are obvious. It will probably be said that in the ordinary school curriculum there is no time for the kind of digression which such a method implies. In so far as this is really the case, it is simply evidence of the fact that more time must be given to science. Actually, however, something can be done even with the curriculum as we know it, by economy of time now being used for practical work of doubtful value. A second probable criticism is much more important. Is not this kind of approach essentially adult in spirit, and completely impracticable with average boys and girls below 16 years of age? To some extent this is a just objection. It will not be possible, perhaps, to exploit the method to the full at the pre-School-Certificate stage, which is, after all, the main part of the business of secondary schools. Nevertheless, two important facts should be realised. Even slight and superficial indications of social function in the presentation of scientific facts may have far-reaching effects on bridging the gap between science and life. As long as Boyle's law (even if "humanised" by a picture of Boyle and perhaps a potted biography) is "science" and the seventeenth-century background is "history" no transfer is possible. But even the most passing indication as to why that particular problem was investigated at that particular time will establish a connection in the mind which may subsequently lead to the right kind of attitude. If no opportunity is lost of dropping hints, even to quite elementary pupils, that there is this close relationship between science and history, and between science and the future, the cumulative effect may be very considerable.

The second point to be borne in mind, before we dismiss as impracticable for schools an approach based on strongly humanist lines, is the unconscious effect of the teacher's own attitude. This is an imponderable but very real force in every department of teaching. If the teacher makes himself aware of the social relationships of science, that awareness will communicate itself to his pupils, however young or "average" they may be, because his whole attitude to the factual content of his subject will be coloured by it. It is, of course, only teachers who have imbued themselves with this social consciousness who will see and make clear the connections between scientific discovery and history, and it is, therefore, ultimately upon such teachers that a new attitude to science in education will mainly depend.

CHAPTER V

THE TEACHING OF SCIENTIFIC METHOD

It has been suggested in earlier chapters of this book that one of the most important functions of school science teaching is the teaching of a scientific attitude of mind, so that our citizens may go out from our schools with a knowledge of the methods by which the study of science has progressed, and with some idea of the ways in which these methods may be applied to the problems of everyday life.

In the earlier years of the school science course this aspect of the subject is probably best treated by the adoption by the teacher of a scientific attitude towards his own work, and by frequent references to episodes in the history of science, as particular examples suggest themselves during the study of the ordinary school syllabus. Some indications of possible methods of treatment have already been given in the previous chapter. There may, however, be opportunities during the post-School-Certificate years to spend part of the time available for science work on a course directly intended to discuss the essential characteristics of scientific methods of thought. These have to some extent been considered already, but in view of the importance of the subject it seems worth while to give an account of an actual sixth form course which has been developed and used for this purpose during the past twenty years. It is intended to occupy two periods a week for the greater part of a term; the remainder of the term is given up to the study of certain periods in the history of science. The majority of the boys who take the course are doing advanced work in classics, history or modern languages; they have already done at least two years' work in science for three periods a week. Every effort is made to get the members of the class to discuss and argue about the subject; they are invited to offer comments and criticisms and made to write their own definitions of many of the phrases used. Wherever possible, experiments are done, or demonstrations given, to illustrate the points under discussion and to relate them to the everyday experience of the class. Some of these illustrations are mentioned in outline. Teachers who may wish to attempt such a course will be able to devise their own experiments without difficulty and draw upon the particular interests of their classes. Suggestions by members of the class will often raise points of interest which appeal to the individuals concerned, and such co-operation is specially valuable in this work.

In the bibliography at the end of the book will be found particulars of some of the books which have proved specially useful in the building up of the course.

The Characteristics of a Scientific Study

We begin by discussing what are the characteristics which entitle a particular study to be called a scientific study. This is perhaps most easily made clear by everyday examples of methods of treatment which all will acknowledge are definitely unscientific. There is usually general agreement that a scientific study begins by the collection of sets of facts about some subject. It is pointed out that the facts are generally obtained by processes which we describe as "observation" and controlled observation or "experiment". Some examples are then given from the history of the seventeenth and eighteenth centuries, when this latter method—the experimental method—began to be widely used in scientific studies, to show how powerful a method it is. Observations made under controlled conditions have enabled us to separate the relevant from the accidental and, so to speak, to cross-examine nature and thereby to discover things which have hitherto remained unknown. It is interesting, for example, in this context to read quotations from the writings of Newton, Franklin and others about lightning, of which the nature had remained a mystery for so long.

The class is then asked to consider how we find out about the external world—about things other than ourselves—through our senses. We have learnt from childhood through touch, taste and smell, and by seeing and hearing.

The facts with which we deal, therefore, come to us through sense impressions which are, in most cases, reinforced and recombined with memories of earlier sense impressions. This idea can be brought before the pupils by questions and by examples. Thus to one observer a piece of coal suggests a hard surface apt to produce black marks and a warm fire; to another comes too the memory of mines and life below the surface of the earth; for a third, there is a vision of the far-distant past when forests of the carboniferous period flourished. The teacher may well ask his class: "Is your mental image, then, like that of your neighbour and are the facts the same for all observers?"

Science is not usually concerned with the nature of the reality which we suppose lies behind the observations we make; that is the province of metaphysics. Natural Science is, however, deeply concerned with the correspondence of the parts of the mental pictures which men form of the external world. Experience has shown that such images will give a self-consistent picture, though often an incomplete one. They are like seamen's charts in that they represent reality in a conventional way. Few people imagine that a map is a complete copy of the country which it portrays; we know that there are many conventions involved and that, for simplicity, much has been left out—but a good map, if wisely used, will bring the navigator to his journey's end, and not him alone but all others who will learn the rules by which the facts of nature have been summarised and made easily available on a map.

It will probably be agreed that when we say that a certain problem is being treated scientifically we are not immediately concerned with the nature of the facts but with the way in which they are being used. There is, however, one general characteristic of all facts which are subject to scientific treatment; they must be such that they can be verified by other normal people. Neither the lunatic nor the lover in their professional capacities are likely to be exponents of scientific method, because for the time being they are not normal. At this point the class can be encouraged to discuss statements such as that of Professor Dingle in his *Science and Human Experience*: "The aim of science is the recording and rational correlation of those parts of our experience which are actually or potentially common to all normal people."

THE METHODS BY WHICH SCIENTIFIC DISCOVERIES ARE MADE

Attention is then given to the question whether there is any general agreement about the essentials of scientific methods.

If we attempt to write down the chief characteristics of a scientific method we might summarise it thus:

(1) The facts of some branch of knowledge are searched out; these facts are classified and the apparently relevant are separated from the accidental.

(2) Gradually there is built up a hypothesis which includes and explains the facts.

(3) Scientists think out new possibilities to which the hypothesis seems to lead and endeavour to test these by further observation and experiments.

(4) If a single fact contradicts the hypothesis, the latter is modified or abandoned. Reasoning must be carried out in search only of the truth, and personal bias and prejudice must be carefully avoided. Facts used to support a hypothesis must be such that they can be verified by other normal human beings.

When put down thus it all seems as simple as the methods of the detective in fiction. Sherlock Holmes collects and studies the curious facts about the busts of Napoleon, he forms his hypothesis and a blow of his hammer reveals the jewel hidden in the last of the Napoleonic heads. In practice, however, each stage of the scientific process has its own special difficulties, and perhaps one of the chief tasks of a course such as this is to make these difficulties clear.

In the first stage—the collection of facts—it must be emphasised that it requires careful training to make accurate observations, and, in recording them, to separate what is actually observed from conclusions which are drawn from the sense impressions which are received. This is doubly difficult when the subject under investigation is one over which we have little or no control. Observations made under favourable conditions are often by no means free from ambiguity. How much less certain are records made by individual observers when the emotions are violently aroused. A reading of the evidence in many a lawsuit will illustrate this.

The class may well be asked to consider how many of them are likely to be reliable reporters of happenings if they were spending a night alone in a house reputed to be haunted. In circumstances under which accurate observation is difficult it is very important to know from experience how the use of instruments can help to check the impressions received by the senses of the observers.

ILLUSIONS OF THE SENSES

The simplest form of sense deception is provided by those optical illusions by which equal lines appear unequal and straight lines seem crooked. A collection of exhibits illustrating these and other optical illusions has been made and it never fails to excite interest. The colour-fatigue effects observed by staring at a brightly coloured surface and then at a white wall also make a general appeal. The class is given the opportunity of seeing a "Blue Moon" by turning towards them for about a minute a bright red light. They then look at a crescent shape of translucent paper illuminated by a shaded flash lamp and see it blue-green, just as many observers have seen a blue moon after looking at a red sunset or at a building on fire. It may incidentally save a nervous person some anxious moments if he knows that curious illusion which causes dimly lit white objects to seem to move relative to a dark background (*Nature*, 23 Dec. 1922).

The weight-size illusion can be convincingly shown by asking a class to write down estimates of the weights of a large block of balsa wood and an equal mass of lead which are passed round so that the two weights can be handled. The results of a recent experiment showed that the average of the estimates of the mass of the lead was double that of the wood.

It is well, too, that our pupils should know that impostors sometimes have carried out "experiments" which have deceived many expert observers. During the great war of 1914–18 a certain man gained much notoriety by taking "spirit photographs" under conditions which many skilled photographers thought were proof against fraud. It was some years later that microscopic examination of the negatives revealed that they showed the same details of structure as reproductions of photographs which had previously been published in a well-known weekly illustrated journal.

It is perhaps permissible also to inculcate some scepticism about the honest but mistaken enthusiast who has persuaded himself of the efficacy of some apparatus or material when he can produce but little evidence to support his "facts". Those who know some of the entertaining stories of Abram's Box will, however, realise how difficult are the paths of those who attempt to throw scientific light on cherished illusions.

THE CONFUSION OF INFERENCES WITH FACTS

The mixture of fact and inference which so often accompanies observations made without instruments can be illustrated by a curious "observation" recorded by Herodotus (Rawlinson's translation, Book IV, paragraph 181):

"The Ammonians have another spring besides that which rises from the salt. The water of this stream is lukewarm at early dawn. At the time when the market fills it is much cooler; by noon it has grown quite cold; at this time, therefore, they water their gardens. As the afternoon advances the coldness goes off, till, about sunset, the water is once more lukewarm; still the heat increases and at midnight it boils furiously. After this time it again begins to cool, and grows less and less hot till morning comes. This spring is called 'the Fountain of the Sun'."

This account of a warm spring can be simply related to the elementary experiment in which a person after placing one hand in very cold and the other in very hot water, say at 40° F. and 110° F. respectively, puts them both into a bowl of lukewarm water at 70° F. Other examples, similar to this, can easily be collected, and pupils should be encouraged to find them in their own reading.

A few people may not find it easy even now to state the fallacy in the argument which van Helmont used in the early seventeenth century when he made experiments to test the very old idea that water was the "element" from which everything was built up. He planted a willow tree of weight 5 pounds in a box of earth which had previously been dried and weighed. The tree was watered with pure water and grew for some years. It was then found to weigh nearly 170 pounds while the earth when dried had only lost 2 ounces in weight. Who could doubt that the tree was formed from water?

The simple way in which alternative possibilities can sometimes be tested by experiment is well shown by the following observations made at an Austrian monastery. There the carp in the fishpond came to the surface to be fed when a monk ringing a bell approached the pond. A visiting scientist obtained permission to remove the clapper of the bell, and when the monk came down to the water-side swinging the silent bell, the fish rose for their accustomed food, whereas when the bell was later rung loudly from behind a screen, they showed no signs of hearing the sound. (*Hearing in Man and Animals*, R. T. Beatty, p. 134.)

THE EFFECTS OF PREJUDICE AND UNCONSCIOUS BIAS

In the gathering of facts and their classification, it is well to remember how, in the past, inherited prejudices have, at times, made some men's minds incapable of a balanced judgment. The following extract is quoted in Lodge's *Pioneers of Science* from the writings of a Florentine who attacked Galileo's discovery of the moons of Jupiter:

"There are seven windows in the head, two nostrils, two eyes, two ears and a mouth; so in the heavens there are two favourable stars, two unpropitious, two luminaries and Mercury alone undecided and indifferent. From which and many other similar phenomena of nature, such as the seven metals, which it were tedious to enumerate, we gather that the number of the planets is necessarily seven."

"Moreover the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore would be useless, and therefore do not exist."

Probably many of us still accept the statements that dew falls and that moonlight is cold, though a moment's consideration will show how unscientific such explanations are likely to be.

It is necessary, therefore, for a scientist to be on his guard against the sometimes unconscious bias which we all too easily acquire from the intellectual climate in which we live. Thus, for example, some writers on eugenics have been accused of making their prejudices respectable by selecting facts to support their opinions, while ignoring other facts which would appear to invalidate the conclusions which they uphold.

The Uses of Hypothesis

The use of hypothesis in correlating large numbers of scientific facts will be familiar to most schoolboys from their elementary work in science. In chemistry they will have learnt that the properties of substances were formerly explained in terms of the four "elements" and how within the last 150 years the atomic hypothesis became so firmly accepted that we now regard it as an established theory.

It is interesting to consider how there have been fashions in hypothesis—the eighteenth century explained the facts then known about heat, magnetism and electricity in terms of "weightless fluids". Gradually new facts were discovered which rendered such ideas untenable and the various hypotheses were modified or abandoned.

As an example of a hypothesis which has changed and shown itself capable of wide extension and growth we might discuss the Ionic Theory from its origins in Faraday's work to its present form. Another example which can be considered with students who have less detailed knowledge is the theory of light. The outline of Newton's corpuscular theory is familiar to most schoolboys. One hundred years after his death it was abandoned because the newly discovered facts of interference seemed inexplicable in terms of it. Now we know that other facts have rendered untenable the particular form of wave theory which supplanted it, so that, for the present, we are developing the quantum theory which relates the properties of waves and particles.

SCIENCE AND TRUTH

There is one aspect of the pursuit of scientific knowledge which is sometimes forgotten and which may well be emphasised by teachers. When Einstein showed that Newton's Law of Universal Gravitation was only an approximation to truth and needed modification in the light of our greater knowledge, the world rightly acclaimed the new theory as a triumph of science. This does not sound strange until we consider some other great discoveries in the history of thought where the attitude of many men could more readily be expressed by "Mighty is Truth and let us do our best not to let it become known". Such lack of faith in truth and in mankind has found its logical conclusion in our own day, when it has been openly proclaimed that truth may be disregarded in national propaganda.

In science it has been found that the pursuit of truth has led to great results. Even from apparent contradiction, new knowledge is often obtained. Thus there has grown up among scientists the feeling that the facts and arguments apparently contradictory to an expected result shall be stated equally with those which support it. To state half the truth or to attempt to suppress part of the evidence is an offence against scientific morality which was, in fact, almost unheard of and almost universally condemned until political and racial enthusiasms in recent years allowed some men to debase themselves in attempts to build up a pseudo-science of race and blood.

It must be suggested in such a course as this that a similar scientific treatment of evidence ought to be adopted in political and social life. This is the time to bring before the class the challenge to morality implicit in the attitude which is prepared to make the worse appear the better reason.

The insistence of science upon ever closer approximation to truth is often ignored by those who maintain that a scientific education is unconcerned with values, and it cannot be too often stressed that by inculcating a profound respect for truth, science is an essential part of any education which aims at appreciation of those ultimate values.

SCIENTIFIC "FACTS" CAN BE VERIFIED

We next consider the necessity for the verification of facts which are to be accepted by scientists. It is usual to consider that a subject cannot usefully be treated as a science unless its "facts" can be verified by normal men, duly instructed where necessary. Experience suggests that where a study is such that its devotees claim that such verification is impossible, it is well to say that the particular subject is not at present suitable for scientific treatment. The wise man is not, however, likely to think of such subjects as for ever fenced off from scientific investigation. In most unexpected ways, methods have been found of applying scientific methods to problems which were once thought to be outside the province of science.

It is interesting to note how some forms of thought have developed into science from origins which seem now to be strangely unscientific. Thus astrology grew into astronomy, though still in places the earlier study has refused to grow up and the astrologer attempts to foretell the future in terms of the positions of the planets and the stars. Meanwhile the belief in magic is dying away in England except in those odd corners, the back pages of cheap magazines!

While the scientist has to be critical of unsubstantiated assertions, he must be able to welcome new discoveries as they arise. The impossibilities of one age are the commonplaces of the next, and the modern Columbus can send back news of his discoveries as soon as they are made.

INDUCTIVE, DEDUCTIVE AND EXPERIMENTAL METHODS

The class is then asked to consider some historical examples of the ways by which science has extended its boundaries.

Methods by which new realms of scientific knowledge have been explored can be classified as inductive, deductive and experimental. Actually it is usual for all three methods to be in use at the same time, though for convenience we often think of them as separate.

The inductive method begins with the collection of large numbers of facts which seem to be connected with a particular phenomenon. From these particular cases, some generalisation is made because it appears to correlate and explain them. The growth of our knowledge of geological epochs and the rise of the idea of evolution illustrate such a method.

The deductive method can be used when a generalisation has been made. It is often possible to deduce a number of consequences which should follow from the "law". Thus Newton, having thought of the Law of Universal Gravitation, was able to show mathematically that a very large number of conclusions could be derived from it. The validity of the arguments used during the process of deduction needs to be tested by seeing whether the conclusions agree with further observations and experiments. The history of human thought shows that subtle errors may creep in unnoticed and be believed in for centuries unless the conclusions are frequently tested by reference to the actual facts of Nature. Thus it was the incorporation of incorrect assumptions about the motion of the planets which finally wrecked the structure of the Ptolemaic system of astronomy. Yet more than ten centuries had passed before Copernicus and his successors showed that the facts did not agree exactly with the long-accepted suppositions.

The conscious use of experiment and observation to check the accuracy of the mental pictures which man builds up to explain his surroundings is a comparatively modern discovery and a most powerful one. We find hardly a mention of it till the time of Roger Bacon in the thirteenth century; then it lies hidden for two centuries and reappears in the writings of Leonardo da Vinci. Finally it came into general use in the late sixteenth century, was popularised in the works of Francis Bacon, and brought with it the modern period of scientific discovery. From that time scientists have tended to alter the form of the questions they address to Nature—the work of science has been largely descriptive. In place of the question "Why do the planets move?" there came the question "How can we most accurately describe their motion?" The sequences of events have been sought out and there has been a growing belief in the Uniformity of Nature. This idea is sometimes expressed in the words: "In like circumstances, similar causes will be accompanied by similar effects." The contrast between the medieval viewpoint and the modern is probably most evident in this connection. We look for uniformity and expect to be able to find that when an effect is unusual there will be a cause previously unnoticed. This attitude of mind has constantly been found to be justified. It is in fact the usual one adopted by the working scientist. There have, it is true, been signs in recent years, however, of thinkers who have done their best to extend the curious physical indeterminacy of the behaviour of electrons into an almost medieval system of philosophy.

THE UNIFORMITY OF NATURE AND THE LAWS OF NATURE

The "Laws of Nature" is a phrase which is liable to mislead those who have no first-hand acquaintance with the ways in which such laws are established. An hour spent in discussing the various laws which the pupils have met in their science work will show that the great majority of scientific laws are carefully chosen expressions intended to summarise a vast number of observations. Yet it is not unusual to find statements that such and such an event occurs because of a certain law, as if the formulation of the law was evidence of some control over the event. If the statement of the law is only a correlation of observed sequences, it seems difficult to justify questions as to whether Nature's laws are ever suspended since, in a sense, the laws are not those of Nature but of man. When events occur which seem to contradict the law, would it not be better to say that our formulation of the law seems to have been inadequate?

It is only gradually and during the course of many centuries that mankind began to realise that in the working of Nature there existed this uniformity and that the heavens did not, in fact, blaze forth the death of princes. Slowly we have been compelled to realise that Nature can only be controlled through knowledge of her ways. We cannot coerce her and can gain control only by "obeying" the laws which we have ourselves formulated. Apparent exceptions to this uniformity have been most fruitful sources of new discoveries, by which we have learned to accomplish things previously unthought of or deemed impossible of achievement.

A course for fairly senior boys such as that summarised above does in fact give rise to discussion and argument on the nature of scientific knowledge and its relation to ordinary experience. Whatever modifications the individual teacher may introduce into such a course, this stimulation of interest and broadening of outlook must be the first concern. There must, however, be much pooling of experience before the teaching of this difficult topic can reach a satisfactory state in our schools. The other aims which the course outlined above tries to serve are to provide a background for any subsequent study of the history of science, and to stimulate the pupils to wider general reading. For example, such books as Whitehead's *Science and the Modern World* or Eddington's *Nature of the Physical World* can profitably be read after such a course has been taken. A number of other books suitable for reading in connection with this part of post-School-Certificate science work are given in the bibliography, many of them now available in very cheap editions.

CHAPTER VI

SUMMARY AND CONCLUSIONS

IT has been said that there is to-day very general agreement that our education should undergo drastic reforms in a number of directions. The war has brought into higher relief the problems facing our educational system; the opportunities for reconstruction which the peace will bring provide a new challenge to our capacity for rapid and constructive educational change. It has been the purpose of this book to emphasise one particular direction in which our present education at all levels is failing to provide an adequate preparation for modern life. On the one hand we have the immense changes in social conditions resulting from the growth of scientific knowledge; on the other we are faced with the manifest deficiencies in our educational treatment of that knowledge. From the criticisms we have made spring naturally certain suggestions for reform so that education may make less difficult and more rapid the transition from an un-scientific economy to one which will make full use of the great opportunities which the new knowledge offers for living the good life.

It is thus the purpose of this chapter to summarise the immediately practicable changes in the teaching of science which would help to make possible a proper contribution of education to social reconstruction.

The majority of men and women are still unconscious of the great potentialities of our increasing control over natural resources and over disease. As a result we acquiesce in conditions which formerly appeared to be the common lot of a great part of mankind, though now they are seen no longer to be inevitable. The social effects of science are not superficial but are effective at the very foundations of modern life. Potential plenty has succeeded want and man has come into a great inheritance. So far, it is true, he has been showing many of the preferences for cheap gratifications which afflict those who pass too suddenly from penury to affluence, and he has neglected much that can give more lasting satisfaction. This, however, is not unexpected, since such conditions are new in the history of the world.

Part of the trouble has been due to the cumulative rapidity with which the new conditions have developed, and we have suggested that it is the province of education to remedy this state of affairs. Since the problems have arisen through the impact of new knowledge, it is surely time that men were made aware of this knowledge and that it should be more consciously used to remove old evils and to modify any adverse conditions to which it has itself given rise. Ignorance of science and lack of a scientific outlook are widespread among the leaders and administrators of the present generation, partly because they have inherited through their educational environment an attitude which is essentially defeatist so that many look back with regret rather than forward with hope and confidence.

The problem of blending a scientific attitude with what is best in our traditional education is complicated by vested interests, which have led many schoolmasters to extol the values of the knowledge they have, at the expense too often of despising that which they do not possess. This danger is greatest in the Public Schools and in the older Grammar Schools, and is there most harmful, since the majority of the statesmen, professional men and administrators have up to the present been trained in these schools. Thus an artificial barrier has been erected between "culture" and knowledge of science, and enthusiasm for bettering the lot of mankind has too often given place to pathetic regret at the passing of the old order. The first necessity if these defects in our education are to be remedied is that all schools should devote adequate time to the teaching of science. The Prime Minister's Committee in its 1918 Report recommended "that in all Secondary Schools for boys the time given to Science should be not less than four periods in the first year of the course from 12 to 16 and not less than six periods in the three succeeding years". It is doubtful whether during the pre-School-Certificate years a number of schools even devote four periods a week for four years, a time which is given as the minimum for the General Science course of the Science Masters' Association. Some schools allow only three years, and a few expect this work to be attempted in two.

This state of affairs is lamentable. No school should be without a carefully planned four-year course in General Science for pupils of 12 to 16 years. The detailed content of the course will depend on the type of school. In any case the general adoption of such a course would involve the raising of the school-leaving age to 16, a change which is already demanded for many other reasons if our education is to provide an adequate preparation for full citizenship in the modern world. We suggest further that science in some form should begin at an earlier age than is usual at present. The child of 8 to 12 years shows usually a natural curiosity and capacity for acquiring facts that is at present scarcely utilised at all in our scientific education. Courses which used these capacities, not only in the study of plants and animals of the countryside but also for elementary work in astronomy and geology, would form a proper foundation for later more rigorous courses on the lines we have sketched. They would give also leisure interests of the greatest value in after-life. This early work should be allotted time which is not often given at present at an age when the natural curiosity of the child (the raw material of a scientific spirit) is most evident.

We feel very strongly that the greatest benefits can only be obtained from science in education if the secondary schools are encouraged to arrange continuous and self-contained courses which in many schools would probably best be organised in two units. The first should be designed to give training in knowledge of facts and in the development of a scientific attitude for those who leave school at 16. We have discussed the content of such a course in Chapter III. The second course would be a continuation of the first and would be for those more able and more fortunate children who remain at school until 18. It should be taken by those who are doing advanced courses in science as well as by those who are specialising in other subjects. If the general four-year course has already been studied, the time needed would probably be two periods a week for two years. We have already suggested some of the topics which can be dealt with in teaching those who have reached an age at which they can begin to appreciate the broader problems of the reactions of science on human affairs.

It will be seen that the allotment of adequate time must be accompanied by changes in content and method and that these changes are already occurring. The need for a wider syllabus which shall include some astronomy and geology with biology, chemistry and physics has brought about the adoption of "General Science" in many schools, though the movement has not yet spread widely enough.

A constant scrutiny of the content of our courses is necessary to ensure that what we are teaching meets the educational needs of the citizens of the coming generation. At present the faults arise mainly from a desire to be too detailed and too rigorous by including too much quantitative work in elementary courses. There has been also too formal a presentation of facts, a failure to relate them closely enough to the present-day world and a lack of realisation of the most important functions of laboratory work, especially for those who will not use their science professionally after leaving school.

Changes in content and in method imply corresponding changes in examinations. Probably the greatest single obstacle to progress in school science teaching is the feeling in the minds of many teachers that they are held so firmly in the toils of preparing for one examination or another that they dare not risk taking the untraditional approach or follow a diversion from their accustomed syllabus, however they might wish to do so in the interest of true education. Such teachers find it difficult to realise that a changed technique does not necessarily mean inefficiency even as judged by performance in examinations as they now are. If we spend some of our time in arousing natural curiosity, in inculcating scientific method, in tracing social connections, it does not necessarily mean that the pupils' retention of facts will be less than if those facts form part of a dull reiteration directed towards "preparing for the examination". Actually a gain in examination efficiency may well result; the time spent otherwise than on cramming may be more than compensated for by increased interest and by awareness of general principles.

Examinations, too, must be changed. The examining bodies are conscious of this and would no doubt be willing to respond if a great majority of science masters were convinced that reform was needed and were agreed on the direction which it should take. At present candidates for scholarships at the universities have to take a general paper in which the candidate is expected to show some knowledge of politics, literature, art and music. Most people will agree that it is right to expect such knowledge from candidates for university scholarships, especially if the home background of the individual candidates is taken into account in assessing the answers. The papers are, in fact, admirable in intention, though the answers to them are not always given the consideration they deserve. Yet such papers rarely include any questions about science, and an immediately possible practical step forward would be to set questions on general scientific topics to all candidates. If such questions were well set and demanded a reasonable factual knowledge and some grasp of the social reactions of scientific progress, it might produce a definite broadening of the education at the top of our schools.

We feel that it is essential that the general education of science specialists should not cease when they leave school. An immediately possible reform would be to provide for all university science students lectures designed to give that historical and philosophical background which is at present so lacking. Such a broadening of the course would require some lengthening of the time spent at the university, perhaps by an additional year. This would also give time for all science students to make some contact with the research side of university work and thereby produce valuable effects on their general outlook, whether their careers be in teaching or administration or in research itself.

The changes we suggest depend for their success on a change in the attitude of mind of many school and university teachers, and the change would affect science teachers as well as those teaching other subjects. There is needed a greater mutual tolerance and a unified view of education. We ought to talk less of cultural and non-cultural subjects, and learn to appreciate all inspiring and sincere teaching even if unfortunately we happen ourselves to know little of the subject, or to have shown no natural aptitude in its pursuit. The scientist should realise how essential to him is a knowledge of history. The classicist or historian must recognise the teaching of science as a part of education as vital as his own, and a knowledge of the contribution of science to contemporary civilisation as a necessary part of the intellectual equipment of his own pupils.

The popularisation of scientific knowledge is of great importance. A large number of books written with this object appear each year and their sales testify to the growing feeling among educated men and women that they should make themselves more aware of the progress of science. Unfortunately many books popularise the latest speculations of mathematical physics rather than contributions of science to everyday life. Relativity, the quantum theory and the principle of indeterminacy appear united in a semi-mystical style which tends to produce a feeling of the remoteness of scientific studies from human affairs. There is, however, encouraging evidence that the need for comprehensible accounts of achievement rather than of speculation is being met by a number of writers, and some useful books of this type are now becoming available in very inexpensive editions. At the same time broadcast talks on similar lines, by experts who can make new discoveries intelligible to the inexpert, are playing an increasingly valuable part in our education.

The reforms we have advocated may seem small beside the great problems of ignorance and the misuse of science with which modern society is faced. Yet few will deny that the basis of social reconstruction is educational, and that Arnold and other great educators of the nineteenth century were right when they emphasised that the seeds of right social conduct are sown in the schools.

We maintain also that the failure of our education to create a worthier society lies partly in the fact that education has not taken sufficient account of scientific progress as a moulding force in our social system. Lack of knowledge of the potentialities of science is frustrating the goodwill which our education in values should develop. No one would hold the view that scientific knowledge alone will make for social progress without such goodwill and much self-sacrifice. The tragedy of the present situation is that the goodwill is often so directionless and impotent.

It is evident that we live in a period of great spiritual unrest and perplexity. Mankind is on the march, as has well been said, and many wonder in what direction it is moving. Science is showing us what can be done for good or ill and some shrink back in fear from the new responsibilities it is thrusting upon us. Surely the present is no time for fear, nor must we leave enthusiasm only to those who have bad causes. Communists, Fascists, and Nazis have in turn invoked the zeal and self-sacrifice of their youth for systems in which we recognise some good mixed with much evil. Have we not ourselves a greater cause which will arouse a like enthusiasm if we can but show to the young a unique opportunity for their service? This is the cause to which many of our schools owe their foundations, a cause made clear nearly two thousand years ago. Now we see it as the cause of individual freedom and self-respect, of self-sacrifice for the common good, of regard for human personality and trust in it, and we associate it with democracy at its best.

Within our own times, this vision of a new order of society has become nearer and more attainable because of the new powers which scientific discoveries have given to mankind. The fields are indeed white for a new harvest; and we have been content that the nations should set their young citizens to reap tares.

Now is the time for the teachers in our schools to show afresh to our children the adventure which is both old and new, the building up of a new world order based on freedom and on love. In the contribution of education to the realisation of this ideal we would contend that to-day the science teacher has a particular responsibility, for it is science that is opening up vast new fields of human service in medicine, in industry, in administration and in education itself.

Whether the natural abilities of our boys and girls happen to be scientific or not, they can appreciate something of the nature both of the problems and of the opportunities which are arising. We must send out our pupils strong in the confidence that they can themselves do something to make the world a better place under conditions in which, for the first time in history, man has great enough control of material things to bring the good life within the reach of all.

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